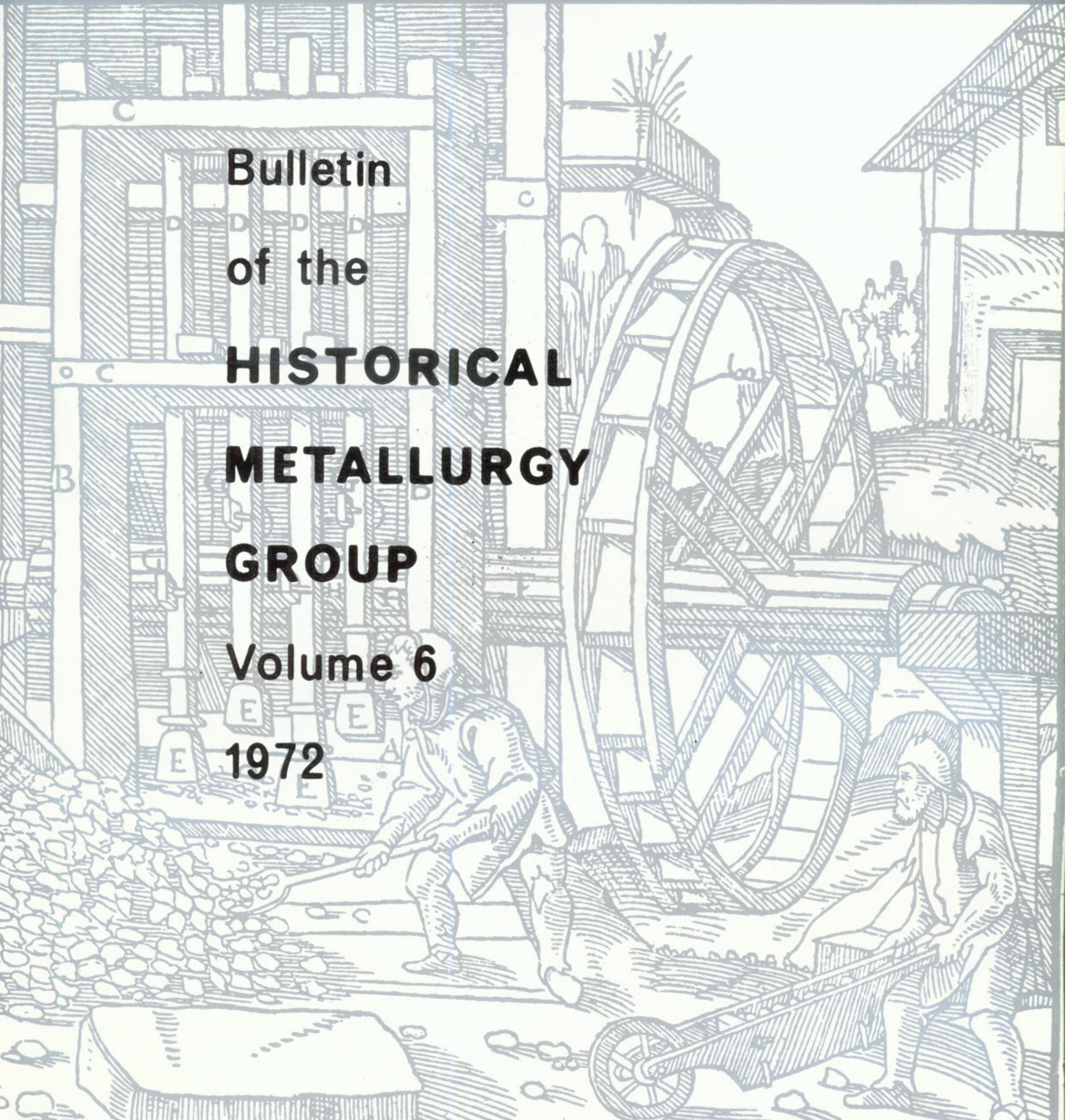

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Contents

The early English iron patents, 1600-1850

TREVOR DAFF

Professor Ashton long ago noted[1] that patent statistics mirror the increased industrialization that was taking place in this country during the years after 1750. And in so far as one seeks a record of inventions emerging during any given period, the patent series is possibly the best source of information. The English patent records are available from the early 17th century onwards, and they provide a continuous, though imperfect, picture of inventive developments throughout the whole of the period of the Industrial Revolution.

Much work, of a varying nature, has been completed using American patent data,[2] and some study has been made of Australian information[3] but the English records remain largely untouched by either historians or economists. Such work as has been done in this country has tended to concentrate upon the history and development of the patent system itself,[4] although the gaps in the literature are about to be reduced by a group of Cambridge scholars.[5]

This lack of attention accorded to patent records may well arise from the very serious difficulties inherent in their use. Some of these problems spring from the very nature of patent systems generally, whilst others are peculiar to particular systems and are rooted in their history.

THE HISTORY OF THE ENGLISH SYSTEM

The term 'letters patent of invention', or more simply patents, is derived from the Latin letterae patentes (open letters) from their being addressed to 'all to whom these presents shall come'. They are simple monopolies granted by the Crown in an effort to encourage technological progress. In return for disclosing his invention, the inventor is given a monopoly in its use for a fixed term of years. After this time, the invention becomes public property. By being charged a fee for the privilege of protection the grantholder is persuaded to work his invention, if only to recover the amount levied.

The English patent system sprang from a policy designed to establish in this country industries that already existed abroad. One of the earliest instances of this is given by the Letters of Protection issued to John Kempe in 1331.[6] In return for the King's protection, Kempe and his Flemish colleagues were to settle in England, and to instruct the English in the mysteries of the new cloth industry. The grant itself contained a promise to all foreign workers to the effect that a similar privilege would be extended to them if they undertook to settle in this country and to teach their arts to any Englishman willing to learn.[7]

The stipulation concerning the instruction of the King's subjects was to remain a condition of patent grants for more than three centuries. Thus, Jeremy Buck's patent, issued under the Commonwealth, ordered that he should take apprentices after seven years of the grant, and teach them the secrets of smelting iron with coal.[8]

This policy of the royal encouragement of industry became a feature of English government as early as Edward III's reign : patents were one of the methods used in applying this policy.

The cloth trade benefited a great deal from such protection of foreign workers, as too did glassmaking, engineering, and clockmaking.[9] Under the Tudors, agreements were made with foreign workers to enter the sovereign's personal service. In this way German armourers, Italian shipwrights and glassmakers, and French ironfounders were persuaded to practise their crafts in this country.[10]

The systematic granting of patents began to emerge during the latter half of the 16th century. The first extant patent which is comparable with a modern grant was that to Henry Smyth on 26 April 1552.[11] By this grant, Smyth was given the sole right to manufacture Normandy glass in this country.

Certainly, by the middle of the century, England provided a ready breeding ground for the development of such a system. The country was integrated under a central authority, and embarking as she was upon an industrial expansion that was to herald the Industrial Revolution proper,[12] England offered a broad market over which an industrial monopoly could reasonably operate.

It was a small, though significant, step from the granting of protection to foreign workers to the elimination of competition for any new industry or process imported into this country by anyone. This decisive move was taken during the reign of Elizabeth I, and under Cecil (Lord Burghley) a recognizable patent system was constructed.

Under Cecil's guidance, patents were granted to stimulate domestic industry, and to attract new manufactures into the realm.[13] Such monopolies, however, were contrary to the Common Law right of freedom to trade, and patents restricting this right could be justified only inasmuch as some consideration moved towards the public at large: patents had to be justified as being in the national interest. It was because many of the grants issued by the Tudors and Stuarts lacked any such consideration that the whole question of patents became so contentious during the early years of the 17th century.

The groundswell of discontent began to be felt during the last quarter of the 16th century, and gradually opposition to the granting of monopolies gathered strength.[14] The Common Law courts were given the right to hear patent cases by Elizabeth's 'Golden Speech' of 1601[15] - previously such cases had come before the Court of Star Chamber - and the first Common Law action concerning patents occurred shortly afterwards.[16] But this did not halt the abuse of the system. Only in 1624, with the passing of the Statute of Monopolies,[17] did the situation show signs of improving.

TREVOR DAFF is with the North-East Somerset Technical College at Radstock, Bath.

The Statute of Monopolies remained the major piece of patent legislation until the mid-19th century reforms, and even today patent law leans very heavily on it. The act outlawed all patents, except those granted to corporations, and those to true and first inventors of a new device or process. Some existing patents, such as Lord Dudley's grant for smelting iron with coal,[18] had their term reduced; new grants were to run for only 14 years.

During the reign of Charles I, the exemption granted to those patents owned by corporations was widely exploited[19]; although later, both King and Parliament came to accept that industry would function far better without monopoly interference. Slowly, the improper use of patents on a large scale began to die out.

During the Civil War, the system was virtually suspended, patent protection being granted by Parliament, as was the case with Jeremy Buck's patent of 1651,[20] and that of John Copley granted in 1655 on a petition by Joseph Wellington.[21]

At the Restoration, Charles II agreed to submit all applications of a mechanical or philosophical nature to the examination of the Royal Society. Much of the heat had been taken out of the patent controversy by this time, and when the 1689 Bill of Rights[22] ended the Crown's claims to override the law, patents were largely removed from the political arena. Thus was created a patent system based upon the royal prerogative, but yet operating independently of the Crown. It was to be two centuries before the patent system generated as much concern again.

England had thus equipped herself with a viable patent system before the Industrial Revolution began. Indeed, one writer[23] has remarked that had not such a system been available, then the Revolution might well have been postponed, or even have found its birthplace in another country, although this is, of course, arguable.

But if patents had become more acceptable, the procedure by which a grant was obtained long remained cumbersome, expensive, and liable to corruption.[24] Separate grants were required for England with Wales, Scotland, and Ireland : the attached list of iron patents refers to the English series. Various extra charges were levied, depending on the number of patentees, the number of words included in the patent, and whether or not protection was sought in the colonies. No public notification was made concerning those grants that had been issued, neither were copies of the patents readily available.

By the middle of the 19th century, the procedure for obtaining a grant had become almost unworkable. In an age when legal reform generally was in the air, when also technical change was accelerating, moves were made to improve the system. But these generated a surprising amount of opposition, especially from those wishing to see the system abolished completely,[25] and the arguments for and against patents raged fiercely even after the situation had been remedied somewhat by the passing of the Patent Law Amendment Act in 1852 [26]

The act reduced the cost of obtaining a patent. It instituted one grant to cover the whole of the Kingdom in place of the three that had been necessary hitherto. The Patent Office was set up to administer the system, and the Patent Office Library was formed, based largely on the work of Bennet Woodcroft[27]; this library has now become the National Library for Science and Invention.

In an effort to make patent details available to all, the specifications were printed and issued to many provincial libraries.[28] All those grants issued from 1617 to 1852 were also printed and published, although the patents issued during the Commonwealth were excluded.

Bennet Woodcroft's compilations of a chronological list of patents, an alphabetical list of patentees, and a subject matter index were updated, and these too were published. His fourth work appeared later, and in this he cited the sources from which the other books had been drawn.[29]

The patent specification, by which the patent device was described and the monopoly delimited, had appeared during the second quarter of the 18th century. With inventors working in the same or related fields, seeking answers to identical or similar problems, it became in the inventor's own interest to describe his device or process in such a manner as to distinguish it from earlier grants.[30]

Two approaches were used : the patent title was expanded to give a brief description, or a short description was incorporated in the recitals that preceded the granting clause. Hence the title of Francis Wood's patent of 1727 (Printed Series No. 489) read "Separating iron from iron-stone or iron-mine by means of sea or pit-coal in an air furnace, and thereby rendering the same as good as iron made with charcoal, and at the same time effecting a saving in the consumption of wood.

But this approach meant disclosing the nature of the invention before patent protection had been obtained, and because of this it was ill favoured by many patentees : a patent's protection became effective from the date of sealing, and not from the date of application. Any prior publication was likely to encourage the invention's use before protection had been received, and this would invalidate the grant once given.

In an effort to avoid this danger, some inventors agreed to publish a description of their invention within a certain time of the patent being granted. The furnishing of such a description was then made a condition of the grant. It was this approach that was subsequently adopted. Many 19th century grants were thus issued on the title alone, be it ever so ambiguous, and the details of the process were given in the specification. A patent for the 'Manufacture of iron' gives no information as to the invention; it is to the specification that one must turn.

The first specification proper is usually taken as that of John Nasmyth, granted on 13 October 1711, for the preparation and fermenting of wash from sugar and molasses (Printed Series No. 387).[31] Whilst Nehemiah Champion's grant of 23 April 1723 (Printed Series No. 454) was the first to carry a clause specifically voiding the grant if the specification was not enrolled within the stated period. His patent was for converting copper into brass.

The first iron patent to carry a specification was that of William Fallowfield in 1727 (Printed Series No. 490). The suggestion[32] that Simon Sturtevant's book 'A Treatise of Metallica'[33] should be taken as the first extant specification is generally rejected, since the text of the book does not explain his invention, but merely seeks to raise some money for his project.[34]

However, the practice of publishing a descriptive specification did not become standard until about 1734 : between Nasmyth's patent and the latter year, only 29 out of 158 grants carried specifications. From this time until the reforms of 1852, patents were granted on the title alone, with the condition that the written specification should be enrolled within six months.

The introduction of the patent specification enhanced the value of the patent records as material for economical and historical analysis, since it enabled the technical details of the device to be ascertained. It is only regrettable that the specification was not in use when the early experimenters were endeavouring to smelt iron with coal. If we had a better idea of the processes they tried much of the argument that has arisen might well have been resolved.

THE DEFECTS OF PATENT DATA

The particular defects of the English patent records depend largely upon the use to which one wishes to put the information, although there are a number of shortcomings that are endemic to patent systems generally. The following discussion will apply particularly to the iron series, although the defects considered can well be applied to any other list of grants.

A careful reading of the patents given in the attached table will show that many important technical advances are absent. Darby's coke-ironmaking process was never patented, although the topic had formed the core of many earlier grants.[35] The puddling improvements of Samuel Rogers[36] and Joseph Hall[37] did not receive patent protection. Neither did the water-cooled tuyere of James Condie, or his hot-blast stove.[38]

So patent data do not provide a complete record of even the major technical advances, let alone the minor improvements. A comprehensive study of the industry's technical development must draw upon alternative sources such as reports in the technical press, contemporary texts, and private correspondence, in an effort to fill the many gaps in the patent evidence. If one accepts Usher's idea of invention as a cumulative synthesis of many improvements, both great and small,[39] then patent data are plainly an insufficient basis for the study of an advancing technology.

The inadequacy of patent records is clearly illustrated in the case of blast-furnace development. The changing in-lines that were employed at different plants over the period were not patented, since the shape of a furnace's lining depends largely upon local factors such as the materials used and the manner of working. But in-lines eventually began to follow more precise general patterns, which experience had shown to be preferable. When John Gibbons finally made his important alterations to furnace lines by extending the bosh upwards and using a round hearth rather than a square one, he did not patent the idea, but wrote a booklet to publicize his experiences.[40]

Again, the effects of throat size upon furnace working were not properly understood until into the 19th century. Furnace throats had been traditionally kept narrow in an effort to conserve heat,[41] but with larger furnaces this often resulted in the temperature of the coke at the tunnel head becoming so intense that severe damage was done to the lining. In an attempt to remedy this, coke was sometimes left to weather to make it less combustible; at some works the fuel was soaked in water before it was charged. It was only when furnace throats were forcibly widened as a result of a series of accidents that the benefits of enlarged throat diameters came to be recognized.[42] But you will look in vain for a record of this development in the patent series.

A further defect of patents is that the issuing of a grant to cover a particular device gives little or no indication of its workability or novelty, notwithstanding that in law these conditions were a fundamental requirement. True, if the patentee of an unworkable device sought legal redress for alleged infringement, then he might be disappointed, but very few grants ever featured in a legal action, so that this test applies to only a handful of inventions. One of the few patentees to have their grants withdrawn on the grounds that the process was not new, was Anthony Hill, whose patent for the use of scale, slag, and cinder in the smelting of iron was set aside.[43]

Many of the early grants were clearly unworkable, being the work of speculators bent on obtaining the maximum of rewards with the minimum of effort. Simon Sturtevant's patent of 1612 for smelting iron with coal was such a one, as were those similar grants issued to other early experimenters endeavouring to substitute mineral fuel for charcoal. Another patent of a speculative nature was that of Francis Wood in 1727, a grant obtained to cover the process of smelting and refining developed by his father William[44] (Printed Series No. 489).

Isaac Wilkinson's patent of 1757 (Printed Series No. 713) for a new type of bellows[45] "wrought by fire or water" heralded the later blowing cylinders with which the names of John Smeaton and the Carron Company are traditionally associated, although blowing cylinders were in use before Carron adopted them in 1766-67. Though Wilkinson's device was to be installed at the newly building Merthyr furnace in 1759,[46] at least one writer has questioned whether the bellows were workable.[47] The question cannot be settled merely by reference to the patent records.

Further important examples of doubtful patents can be cited concerning the puddling process developed by Henry Cort at his Funtley works. During the opening years of the 19th century, when efforts were being made to alleviate the penurious condition of Cort's family,[48] various ironmasters sought to detract from Cort's claims by asserting that the puddling process had been invented before his patent of 1784 (Printed Series No. 1420).

The grants of the Cranage brothers, dated 1766 (Printed Series No. 851), and of Peter Onions, dated 1783 (Printed Series No. 1370) were raised to support the opposition's case, but it is likely that these processes had been abandoned or were floundering before Cort had completed his experiments. Letters passing from Coalbrookdale, where both the Cranages and Onions had conducted trials, to Cort at Funtley confirmed that little success had been achieved at the former works.[49] The failure of the earlier processes to perform what was claimed for them cannot be ascertained from the patent data alone.

Even the grant of Thomas Botfield, taken out in 1828 (Printed Series No. 5596) was tested his invention, but merely seeks to raise some money for his project.[34]

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Even the grant of Thomas Botfield, taken out in 1828 (Printed Series No. 5596) was tested of using or installing the process was too great. The patented process of David Mushet and William Crawshay in 1815 (Printed Series No. 4248) covered the extraction of iron from the slags thrown off in the production of copper. But, though the process was successfully tried at Cyfarthfa in 1818, it demanded a much longer processing time than did normal methods and conventional materials. The copper slags contained large quantities of silicon deriving from the use of sand as a flux in copper smelting; this high silicon content called for a double smelting process to remove the impurities, and this added to the costs of manufacture.[57]

Although the early puddling patents of Onions and Cort had considered the use of molten pig in the wrought ironmaking process, the practice grew up of charging cold pig to the puddling furnaces. Even where blast and puddling furnaces were situated on adjacent sites, the iron was usually cast into the pig beds, allowed to cool, and then broken before being taken to the forge. This was an inefficient method working, since the heat built up in the blast furnace to render the iron molten was then dissipated, and the puddling furnace or refinery was required to remelt the iron before decarburization or desiliconization could begin.

The patents of Jones, Foster, Booker, and Jones, in 1832 (Printed Series No. 6300), Josiah John Guest in 1833 (Printed Series No. 6379), Thomas Booker in 1841 (Printed Series No. 8855), and of Powell and Ellis in that same year (Printed Series No. 8935) were all concerned with the use of molten or as-cast iron in the puddling or refining furnaces. But to the industry as a whole, such practices were not easy to adopt, since they often required re-siting the puddling furnaces closer to the blast furnaces, and at the older works this demanded quite a large capital outlay.

Some grants, the fate of which is unsure, carried with them the seeds of later developments. In 1802, James Birch considered the idea of providing a blast furnace with two tapholes (Printed Series No. 2608) and, although evidence concerning the adoption of this layout is lacking, it is interesting to note that the British Steel Corporation's new Llanwern furnace in South Wales is to be so designed.[58]

As early as 1825, Philip Taylor was considering hydrogen injection at the blast-furnace tuyere by using either the pure gas or oil (Printed Series No. 5244). John Dawes followed this in 1835 with his scheme for using carburetted hydrogen (Printed Series No. 6948), and he was succeeded in 1838 by William Barnett, who suggested the use of coal tar (Printed Series No. 7727). Ivison in the same year (Printed Series No. 7578) and Angier Perkins five years later (Printed Series No. 9664) both proposed the use of steam injection.

Neither was blast enrichment confined to the use of gaseous or liquid substances : John Dawes considered the use of charcoal, coke, ore and fluxes in his specification of 1831 (Printed Series No. 6207). Similar ideas were included in the grants of Samuel Banks in 1840 (Printed Series No. 8479) and of Moses Poole in 1847 (Printed Series No. 11810).

On a different topic, Anthony Hill in 1817 acquired a patent (Printed Series No. 4151) for a process very similar in principle to the spray steelmaking approach currently being developed by BISRA.[59] As-cast pig iron was run into a container shaped like a colander. From here the metal fell in droplets into an air blast before falling into a tank of water. In this way, Hill claimed to be able to accelerate the conversion of pig iron into bar iron although his metal was still to be puddled after this treatment.

Finally, it is necessary to consider the problem of weighting : just as not all patented devices are workable, so not all those that are workable are of equal importance. The kind of interpretation that one places on the word 'importance' will naturally depend upon the criteria being used. However, criteria notwithstanding, patented devices cannot be assumed to be homogeneous entities. Not all devices will have the same effect upon the production functions. The effect of devices not taken up will be virtually nil, except inasmuch as they pave the way for future devices.

But the task of assigning weights to the devices becomes so intractable that most writers, after noting the problems, go on to assume them away. For just what basis does one adopt for allocating weights to such disparate items? How can one compare a patent such as say Neilson's, with that of Dud Dudley ? Or, to take a more meaningful comparison, that of Neilson with George Crane's ? Crane's process would only function if use was made of the hot blast and this he was allowed to do under an agreement with the hot blast patentees. The problem is serious, because as with many other limitations of patent records, it clearly undermines the results of any analysis based upon patent data.

Some writers[60] have doubted whether patent information can be usefully employed at all, since the defects are so serious, and many of them fundamental. This seems to be too pessimistic a view.[61] The patent series does provide a unique, albeit an haphazard, record of inventive developments over the period from the early 17th century. In so far as one seeks such a record, the series is often all that one has. Of course, it must be used with care, but provided that the limitations are constantly borne in mind, there is no reason why the information should be ignored completely.

THE IRON PATENTS

Endeavouring to assign an invention to a particular industry can be a hazardous occupation for at least two reasons : first, some devices lend themselves to many, varied uses, and secondly, the term 'iron industry' is itself not easy to define.

In the case of the iron industry, the smelting of the ore would naturally qualify for inclusion, but some of the finishing branches of the trade, far removed from the primary processes, would be doubtful items. So too would some of the ancillary processes and equipment. For instance, the development of the steam engine and its subsequent adoption has a profound effect on the industry, but the list of patents below excludes it, because it was strictly speaking not an iron invention : it was not designed specifically for use in iron manufacture.

Neither were developments in cokemaking practice aimed specifically at the iron industry, so that these too have been excluded, and yet improvements in the quality of fuel added materially to the industry's advance over the period.

The series also excludes those grants whose main concern was with steel manufacture. To study the technical development of the steel industry would demand that the time horizon be pushed forward to the present day so that the work of Bessemer, Siemens, and Thomas and Gilchrist could be set against the improvements gained by the oxygen processes.

But if the iron industry is difficult to define, the term does convey a meaningful idea of what is being discussed, even though opinions may differ over where the demarcation lines should be drawn. If the industry is taken to include smelting, forging, and rolling, and also to encompass the malleable iron trade, then the attached list pf patents may be acceptable as being possibly the most strongly defensible of any. Although amendments could be made, it is suggested that any alterations founded upon a rational basis would not affect the general nature of the study.

The attached list of patents was extracted mainly from the books of Bennet Woodcroft, and the later abridgment of iron and steel patents.[62] Those grants issued before 1617 have been culled from the Calendar of State Papers Domestic. The Commonwealth grants have already been cited.

In the graphs, the general series represents all patents other than iron patents. This series has been taken from Mitchell and Deane's book on historical statistics.[63] The number of iron patents subtracted from the total number in each decade provides the general series.

As the history of the patent system has shown the granting of industrial monopolies for new devices did not begin to settle down until after the middle of the 17th century. A period of intense political unrest culminating in the Civil War had serious consequences for the patent system, coming as it did at a time when the system itself was still being formulated. For this reason, although the list of iron patents begins at 1600, the graphs have been drawn from 1660.

The dramatic increase in the number of grants issued over the period is clearly shown in Fig. 1. The general series began to increase during the 1730s; before this date the number of grants had been increasing only slowly, producing an irregular curve. This slow rate of increase continued from the turn of the 18th century until the 1750s. Then, suddenly, during the period 1750-60, the number of patents increased sharply, and began a climb which it maintained throughout the period to 1850 and beyond. It was not until the middle of the century that any indication was given that the movement of patents was anything other than a normal cycle.

On the other hand, the iron series continued to follow the cyclical path that it had been developing for itself since the late 17th century. The cycle which began in 1770-80 marked the beginning of the take-off for the iron patents, but this looked like just another cycle until 1800-10, when the series began to increase sharply, an increase that was accelerated during the decade 1830-40.

The change in patent law at this time, and the onset of the new metal, steel, makes comparisons after 1850 difficult to make. For instance, under the new regulations which reduced the cost of a grant, the number of patents issued increased sharply. In 1850 the number of grants was 513; three years later it was 3045.

The iron industry, too, soon came to be the handmaid of the steelmakers : the quality of the iron produced came to depend upon the demands of the steel furnaces. The years up to 1850 cover virtually the whole of the period of the iron industry qua the iron industry. After this time, the fate of iron and steel became so intertwined that it soon became meaningless to talk of them as separate industries.

To study the causes of the steep increase in patents from the middle of the 18th century is to become embroiled in a comprehensive examination of the Industrial Revolution itself. This is a Gordian knot that has occupied generations of historians. But inventions do constitute factors of production just as much as do the more traditional items of land, labour, and capital; although inventions have a special character of their own in that they seek to change the relative proportions of the other factors in the production function.

The demand for a factor of production is essentially a derived demand. It is founded upon the demand for the finished product. Inventions are no exception. They are required by entrepreneurs, not for their own sake, but to assist in producing the necessary goods and services. The extent to which an invention will be used will depend upon the relationship between its marginal revenue product and its price. If there is no market for the invention's finished product, then no matter how cheaply the invention can be obtained, entrepreneurs will not be interested in using it. Conversely,the wider the market for an invention's finished good, the wider the market for the invention itself.

Market conditions will therefore tend to determine both the number and the nature of the inventions that are adopted. And, in so far as inventors are motivated by the prospect of economic gain, they too will also be so influenced.

The problems of charcoal supplies during the early 17th century attracted inventors to seek alternative fuels. Whether the situation was as bad or as widespread as some would infer, it certainly caused some questioning of traditional methods, and the list of early grants bears witness to this.

During the 18th century, the demand for wrought iron in this country had increased to such an extent that the old finery process was unable to keep pace. The domestic market came to rely heavily upon imports from Sweden and Russia,[64] a dangerous expedient in times of political unrest, and always one calculated to drain the nation's wealth.

As the demand for wrought iron increased, this position threatened to worsen. To anyone successful in producing wrought iron at home in greater quantities than hitherto, the potential rewards were great. Inventors came forward with their ideas until Cort and his contemporaries managed to carry their new methods into practice. After this time, because the metal was so much sought after, because so much capital came to be sunk into its manufacture, inventions to improve the process continued to be forthcoming.

The effects of demand upon patents is also apparent when considering railway materials. The railway boom of the middle of the 19th century encouraged inventors to patent various methods of producing rails, and during this time numerous iron patents included railway materials in their specifications.

The number of patents, as opposed to their nature, was also partly affected by market forces. This is illustrated by the manner

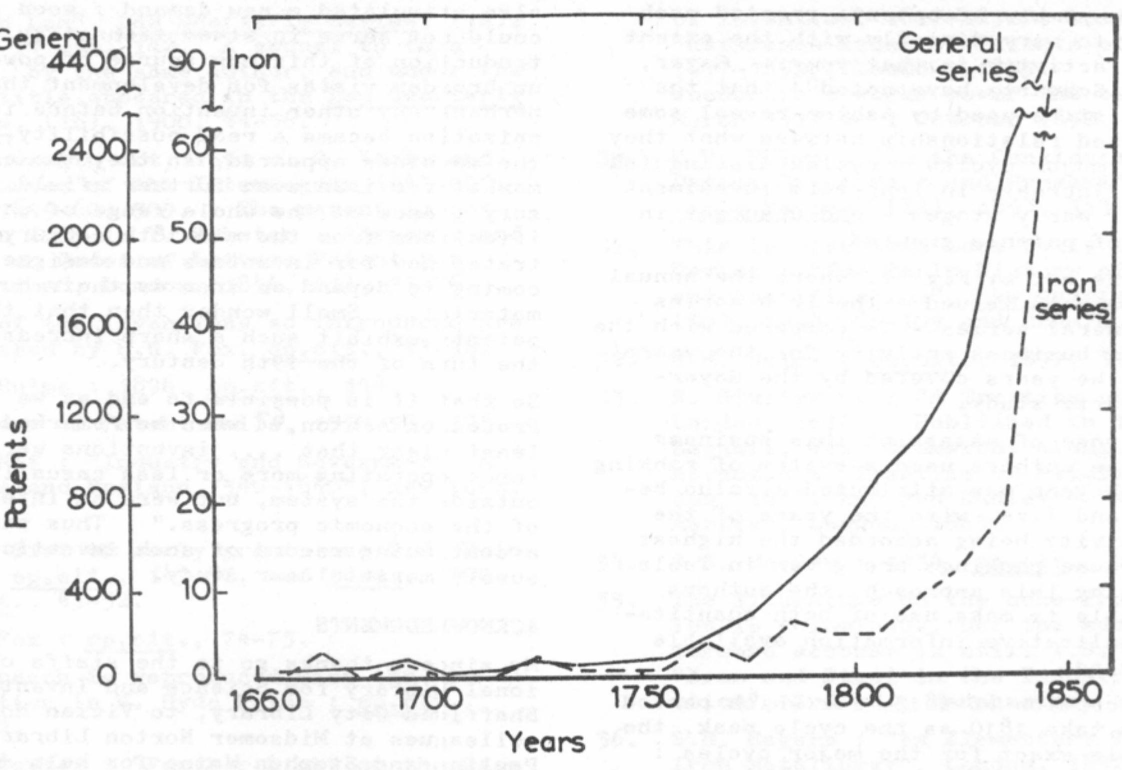

Fig. 1 General series and iron series, 1660-1850 (decennial totals)

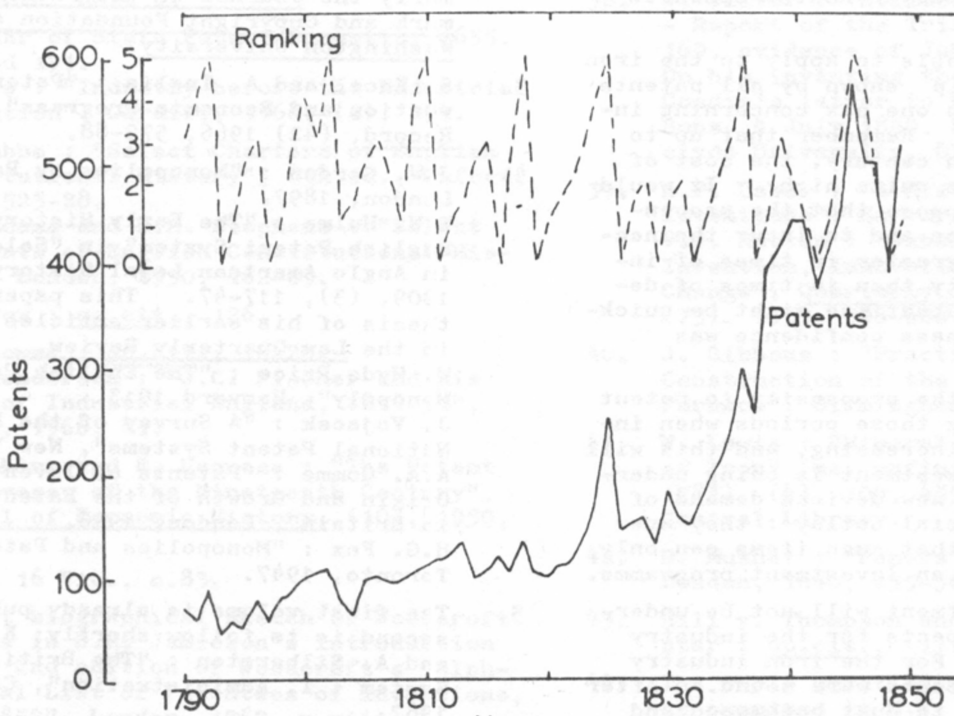

Fig. 2 Patents and business activity, 1790-1850

in which the number of patents granted each year tended to vary directly with the extent of business activity in that year. Gayer, Rostow, and Schwartz have noted[65] that the patent statistics used by Ashton reveal some clearly marked relationship between what they describe as major cycles - cycles distinguishable by the increase in long-term investment during their early stages - and upsurges in the number of patents granted.

This is borne out by Fig. 2, where the annual number of patents issued - the iron series plus the general series - is compared with the intensity of business activity for the years 1790-1850, the years covered by the Gayer-Rostow-Schwartz study.

For the purpose of assessing this business activity, the authors used a system of ranking wherein each year was attributed a value between zero and five, with the years of the highest activity being accorded the highest number. These rankings are given in Table II. By using this approach, the authors have been able to make use of both quantitative and qualitative information available for the period.

With the exception of 1813, for which period the authors take 1810 as the cycle peak, the conformity is exact for the major cycles : the relationship shows up during the peaks of 1792, 1802, 1818, 1825, 1835, and 1845. The relationship also applies well during the minor cycles with the exception of 1811-16 and 1836-42.

However, when the annual number of iron patents is compared to Beveridge's index of the iron industry's activity over the period 1790-1829,[66] the relationship appears imprecise, largely because of the paucity of iron patents during the early 19th century. It must be borne in mind, too, that the period chosen by Beveridge includes the years 1811-16, which fares badly under the Gayer-Rostow-Schwartz analysis.

How far it is justifiable to apply to the iron series the relationship shown by all patents depends upon the ideas one has concerning inventions and patents. Remember that up to the middle of the 19th century, the cost of obtaining a patent was quite high. It would seem reasonable to suppose that the propensity to patent a device and to incur the necessary cost would be greater in times of intense business activity than in times of depression, since the patent fee might be quicker recouped when business confidence was buoyant.

It seems likely that the propensity to patent will be greater during those periods when innovating activity is increasing, and this will tend to occur when investment is being undertaken. Indeed, most new devices demand of themselves some financial outlay : they are capital embodied, so that such items can only be adopted as part of an investment programme.

Of course, such investment will not be undertaken unless the prospects for the industry appear to be sound. For the iron industry after 1750 these prospects were sound. After this time, iron began to oust both wood and stone in the everyday life of the community, and it began to create new markets of its own. The famous iron bridge across the Severn, although it bears the unmistakable marks of a bridge designed for stone construction, did point the way events were to follow during the 18th and 19th centuries.

The coming of the steam engine, though it assisted in the product on of iron, yet it also stimulated a new demand : wood and stone could not serve in steam technology. The introduction of this new source of power opened up broader vistas for development than had perhaps any other invention before it. Mechanization became a real possibility, and as the machines appeared, so they too carried the market for iron even further afield. A cursory glance at the whole range of patent specifications from the mid-18th century illustrates how far inventors and designers were coming to depend on iron as their building material. Small wonder then that the iron patents exhibit such a sharp increase after the turn of the 19th century.

So that it is possible to end as we began, with Professor Ashton,[67] when he remarked "It is at least clear that .... inventions were not a force operating more or less casually from outside the system, but were an integral part of the economic progress." Thus patents, as a continuing record of such inventions, must surely merit closer study.

ACKNOWLEDGMENTS

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TABLE I Decennial Totals of Iron and Other Patents 1600-1850

Decade	Iron Patents	Others	Total
1660-70	--	31	31
1670-80	7	44	51
1680-90	--	53	53
1690-1700	3	99	102
1700-10	--	22	22
1710-20	--	38	38
1720-30	5	84	89
1730-40	2	55	57
1740-50	2	80	82
1750-60	2	90	92
1760-70	8	197	205
1770-80	5	289	294
1780-90	13	464	477
1790-1800	10	638	648
1800-10	10	915	925
1810-20	18	1106	1124
1820-30	25	1437	1462
1830-40	38	2415	2453
1840-50	88	4493	4581

TABLE II Business Cycles and Patents 1790-1849

Year	Patents	Rating	Year	Patents	Rating
1790	68	3	1820	97	1
91	57	4	21	109	1.5
92	85	5	22	113	2
93	43	0	23	138	3
94	55	1	24	180	4
95	51	2.5	25	250	5
96	75	3	26	141	0
97	54	0	27	150	1.5
98	77	1	28	154	2
99	82	3	29	130	0
1800	96	4	1830	180	1.5
1	104	3	31	151	2
2	107	5	32	147	0
3	73	1	33	180	1
4	60	1.5	34	207	2
5	95	2.5	35	231	3
6	99	3	36	296	5
7	94	2	37	256	0
8	95	1	38	394	1
9	101	4	39	411	3
1810	108	5	1840	440	2
11	115	0	41	440	1
12	118	1	42	371	0
13	131	1.5	43	420	1
14	96	2.5	44	450	3
15	102	3	45	572	5
16	118	0	46	493	4
17	103	3	47	493	2
18	132	5	48	388	0
19	101	0	49	514	1

THE ENGLISH IRON PATENTS 1600-1850

Date	Number	Patentee(s)	Subject
1607	---	Robt. Chantrell	Use of mineral coal in iron manufacture
1612	---	Simon Sturtevant	Use of mineral coal in iron manufacture
1613	---	John Rovenzon	Use of mineral coal in iron manufacture
1621	18	Edward, Lord Dudley	Smelting iron ore and making cast iron or bar iron with sea-coal or pit-coal in furnaces with bellows
1627	38	William Astell John Copley Francis Crofts	Melting iron ore and making the same into cast works and bars with sea-coal and pit-coal
1630	50	David Ramsey	To make hard iron soft
1630	51	Edward Ball Edmund Lassells Robt. Hampton William Auley	Melting, making, fining, and burning iron, lead, and tin and other things with peat or turf prepared for the purpose
1632	61	Edward Jorden	Melting lead, tin, iron, and copper ore with pit-coal, peat, and turf
1633	65	Sir Abraham Williams et al.	Preparing fuel for the manufacture of iron
1635	83	Capt. Thornesse Francke	Making furnaces for smelting and melting copper, tin, lead, and iron
1636	91	Sir Phillibert Vernatt	Making, melting, and smelting iron, brass, steel, copper and other metals with a fire of seal-coal, pit-coal, or stone-coal, without charking, or mixing the same with charcoal, or by the use of any other fuel except wood, or fuel made from wood
1637	113	Sir Phillibert Vernatt Capt. Thomas Whitmore	Making good and merchantable tough iron according to the nature of the mine, with sea-coal or peat, and with one-fifth of the expense of charcoal as now used.
1638	117	Sir George Horsey David Ramsey Roger Foulke Dud Dudley	Making iron into any sort of cast works with sea or pit-coals, peat or turf, and with the same to make the said iron into plate works or bars
1651	---	Jeremy Buck	Patent for smelting iron with stone-coal
1655	---	John Copley	Grant of right to make iron with charked pit-coal
1670	161	Prince Rupert	Softening cast iron so that it may be filed and wrought like forge iron
1671	164	Prince Rupert	Softening cast iron so that it may be filed and wrought like forge iron
1671	165	Prince Rupert	Softening cast iron so that it may be filed and wrought like forge iron
1673	170	Sir Nicholas Slanning	Melting iron ore and other metals with turf and peat, charked
1677	198	Frederick de Blewstone	Forging iron and all metals and minerals by the use of pit-coal and sea-coal
1678	207	Thomas Harvey	Engine for drawing Spanish and Swedish iron into all sorts of rounds for bolts
1692	291	Thomas Addison	Use of sea-coal and pit-coal for smelting iron ore, stone, flags, cinders, old iron and other materials
1696	348	Evan Jones	Engine for blowing the bellows and working the hammers in melting and forging iron, copper, and other metals
1699	363	John Hill Oliver Hill	Smelting ores in the Hungarian manner, with or without bellows
1724	460	Roger Woodhouse	Rendering cast iron malleable by means of coals without coking
1727	489	Francis Wood	Separating iron from ironstone or iron mine by means of sea or pit-coal in an air furnace and thereby rendering the same as good as iron made with charcoal, and at the same time effecting a saving in the consumption of wood

1727	490	William Fallowfield	Smelting or melting down iron ore, and refining and drawing out the same into bar iron by means of fuel different from any that has before been used for the purpose
1728	502	William Wood	Making raw iron, or iron metal prepared in an air furnace with pit-coal immediately from the ore
1728	505	John Payne	Making pig iron malleable, and drawing the same into bars by the use of the forge hammer
1736	553	Kingsmill Eyre	Making raw iron or iron metal from ironstone or ore in air furnaces with pit-coal
1738	565	Isaac Wilkinson	Bellows of cast metal for forges, furnaces, or any other works
1742	582	John Baskerville	Rolling, grinding, and moulding metal plate to be japanned or varnished for various purposes
1748	637	Malachy Postlethwayt	Casting iron from ironstone or ore, purer, tougher, and more nearly approaching to forged iron than heretofore, by a peculiar application of fire, and also of salts and other ingredients
1757	713	Isaac Wilkinson	Machine, or bellows to be wrought by fire or water
1759	740	Thomas Blockley	Polishing and rolling malleable metals into different forms, and making tyres for carriages
1761	759	John Wood	Making malleable iron from pig or sow metal
1762	780	John Roebuck	Making malleable iron from pig or sow metal
1762	783	James Knight	Making and drawing iron and other metals by a new kind of wood bellows
1763	794	John Wood Chas. Wood	Making fused or cast and cinder iron malleable with raw pit-coal
1765	822	John Scott	Making pig iron from one certain mineral
1766	851	Thomas Cranage George Cranage	Making pig iron or cast iron malleable in a reverberatory or air furnace with pit coal only
1766	854	John Purnell	Machine for making ship's bolts and round rods, and wire of iron and steel
1769	935	Richard Ford	Rolling metals of various thicknesses with the same rollers by one operation, drawing wire and stamping metals
1771	988	John Cockshutt	Bloomery for making and refining iron
1773	1041	John Barber	Machine and apparatus to extract metals from ores, and collect the particles when volatilised by means of fire, water, air, and steam
1773	1054	John Wright Richard Jesson	Making malleable iron from cast iron and other cast metal with raw coals or coke, without charcoal granulations, mixtures of fluxes, or other infusions
1774	1063	John Wilkinson	Casting and boring iron guns and cannon
1778	1194	John Talbot	Machine used in the working of steel, iron, brass, and copper, hot or cold
1781	1279	James Reeves	Making various specified implements by casting pig iron alone, or mixed with steel or other metal, and subsequent tempering
1783	1351	Henry Cort	Furnace for preparing and welding iron
1783	1360	George Matthews	Making cast iron malleable and suitable for making cannon etc.
1783	1362	John Bradley	New invented forge back, tew iron, and frame on a new construction for conveying wind by the blast of bellows or otherwise
1783	1370	Peter Onions	Refining cast or pig iron and converting the same from a fluid state into wrought or bar iron
1783	1396	Richard Jesson	Making bar iron from cast iron by the use of coals or coke, without charcoal

1783	1398	John Westwood	Hardening and stiffening copper, brass, iron, steel, etc., and reducing the same (when cold or heated) into round, angular, indented or oval forms, by using grooved or indented rollers
1783	1408	William Playfair	Cutting or dividing, and giving to metal cylindrical or other uniform or tapering shapes, in making bars, bolts, rods, wire, etc., producing figured surfaces
1784	1420	Henry Cort	Shingling, welding, and manufacturing iron and steel into bars, plates, and rods of purer quality, and in larger quantity than heretofore, by a more effectual application of fire and machinery
1785	1485	James Watt	Methods of constructing furnaces or fire-places for heating, melting, and smelting metals and their ores whereby greater effects are produced from the fuel, and the smoke is in great measure consumed
1786	1536	John Butler	Making bolts and rods of iron, copper, or brass, or from iron shearings
1787	1608	William Purnell	Preparing, shingling, and welding iron with coal from the ore, or pig or other cast iron by means of a machine
1788	1642	Robert Gardner	Air furnace for manufacturing iron, copper, and other metals
1792	1857	John Wilkinson	Rolling or flattening of iron and other metals by means of steam engines or any other power
1792	1869	Samuel Lucas	Bringing iron ore and calx of iron into a metallic state without first rendering the same fluid
1792	1892	William Fullarton	Reducing or refining cast iron into malleable or wrought iron
1792	1928	John Barber	Smelting ironstone and other metallic ores, and the calx thereof, by steam, air, and fire, impregnating the same with inflammable air, thereby producing a tough metal
1793	1966	William Taylor	Air furnace for making iron
1794	1993	John Wilkinson	Making cast metal or pig iron from the ore for the purpose of making it into bar or malleable iron
1798	2293	John Champion	Making wire from rolled and slit iron
1798	2244	John Hazledine	Reducing and forming pigs and pieces of iron, copper, brass, and other metals into bars, plates, and hoops
1798	2272	Robert Hindmarsh	Applying an elementary or physical power to blast furnaces and other works where power is required
1799	2287	James Edgell	Use of metal of a peculiar quality, and great strength in place of common iron, where lightness and strength are required
1800	2447	David Mushet	Process applicable to the manufacture of metals from the ore into bars, ingots, or otherwise, and to the completion of the various articles usually made of such metals
1801	2482	John Bennoch	Machines for making nails, bolts, rods, springs, and metal plates
1802	2608	James Birch	Furnace for smelting and making pig iron
1802	2645	Joseph Hately	Reducing fluxes for purification of minerals and metallic substances (use of salt)
1804	2767	Samuel Lucas	Rendering cast iron malleable
1804	2775	Edward Martin	Making bar iron by means of coals, culm, and raw stone
1805	2888	John Hartop	Preparing malleable iron for making bars, sheets, and slit rods, and manufacturing the same into hoop iron
1808	3097	John Wilkinson	Making pig iron from ore, which when made into bar iron equals that from Sweden
1808	3149	William Proctor	Melting and using wrought iron or steel

1809	3197	Anthony George Eckhardt	Casting metallic and other bodies (spinning)
1810	3296	David Cock	Vessels for melting metals
1810	3326	James Fussell	Making and working forge and other bellows
1811	3449	John Street	Making and working bellows
1812	3569	Jeremiah Dimmack	Iron in all its stages (use of blast in puddling furnaces)
1812	3601	John Brown	Making rods and hoops from old iron hoops
1814	3825	Anthony Hill	Smelting and working iron (use of scale, slag, and cinder)
1815	3901	Richard Smith	Smelting iron, lead, or copper ores, and other minerals or metallic substances, and manufacturing iron
1815	3907	William Bell	Manufacturing wire
1815	3944	David Mushet	Manufacturing iron (finers' iron)
1816	4050	John Poole	Working plated iron or steel into plates, bars, or other articles
1817	4149	John Hawks	Making iron rails for railways
1817	4151	Anthony Hill	Working iron (action of blast on a finely divided, falling stream of iron)
1818	4248	William Crawshay David Mushet	Making bar or other iron from slag or cinders produced in smelting copper ores, and manufacturing copper
1818	4256	Thomas Jones Charles Plimley	Blowing engines
1818	4257	Thomas Todd	Rolling iron and making wire, nails, and screw
1818	4258	William Church	Machinery for making nails, spikes, screws, and wire of iron, copper, or other metal
1819	4371	James Hollingrake	Casting and forming metallic substances, sounder and closer in texture
1819	4397	John Thompson	Extracting iron from ore
1820	4503	John Birkinshaw	Manufacturing a wrought iron railway
1820	4504	William Taylor	Furnace for melting iron and other ores
1820	4518	George Vaughan	Blowing machine for fusing and heating metals. smelting ores, and supplying blast for other purposes
1821	4538	James Foster	Manufacture of wrought iron or malleable iron
1822	4634	Richard Summers Harford	Puddling iron
1822	4663	Richard Summers Harford	Heating processes in the manufacture of bar, rod, sheet, or other malleable iron
1822	4667	William Danniell	Rolling iron into bars for making tin plates
1822	4697	David Mushet	Manufacture of iron from certain slags and cinders produced in the working or making of that metal
1822	4713	William Jones	Manufacturing iron (puddling)
1823	4865	Robert Stein	Construction of blast furnaces and apparatus connected therewith
1824	4913	William James	Construction of (hollow) rails and tramways
1824	4932	Joseph Spencer	Construction of furnaces and forges for the preparation of iron or steel, and for the process of manufacturing nails and other articles
1824	4953	William Church	Apparatus used in casting iron and other metals
1824	4956	Joseph Lucock	Manufacturing iron by common salt
1824	4968	Richard Horton	Manufacturing wrought iron
1824	5031	John White Thomas Sawerby	Air furnace for melting metallic substances
1825	5084	William Church	Casting of cylinders, tubes, and other articles of iron, copper, etc.
1825	5182	Charles Powell	Blowing machine
1825	5244	Philip Taylor	Making iron (introduction of carburetted hydrogen to furnace)

1827	5467	William Jefferies	Calcining and smelting, or extracting metals and semi-metals from ores
1827	5546	John Hague	Working cranes and tilt hammers by connecting a piston to the helve
1828	5596	Thomas Botfield	Smelting and making iron
1828	5701	James Beaumont Neilson	Application of air to produce heat in fires, forges and furnaces where bellows or other blowing apparatus are required
1828	5704	William Losh	Forming iron rails and chains for railroads
1829	5779	Josiah Lambert	Making iron, applicable at the smelting of the ore, and at subsequent stages up to the completion of the bars
183)	5893	Josiah Lambert	Making iron, applicable at the smelting of the ore, and at subsequent stages up to the completion of the bars
1831	6207	John Samuel Dawes	Manufacture of iron (furnace additions)
1832	6299	Daniel Horton George Horton	Puddling furnace for the better production of manufacturing iron in the process of obtaining it from the pig iron
1832	6300	George Jones James Foster John Barker John Jones	Making of malleable iron (the charging of molten iron to the puddling furnace)
1833	6374	John Samuel Dawes	Manufacture of iron (mixing iron oxides with coal, charcoal, etc.)
1833	6379	Josiah John Guest	Reducing iron ore and other materials containing iron to what is called in the iron trade 'fines'
1833	6457	Robert Smith John Walkinshaw	Rails for railways
1835	6807	James Hardy	Manufacture of axletrees, and other cylindrical or conical shafts
1835	6837	Charles Schafhautl	Manufacture of malleable iron
1835	6901	Charles Pierre Devaux	Smelting of ironstone or iron ore (use of hot blast)
1835	6908	David Mushet	Making bar or malleable iron (improvements in puddling)
1835	6948	John Samuel Dawes	Making of iron by the application of certain known materials; preparing such materials; recovery of products in the manufacture of iron (hydrogen injection)
1836	6995	Frederick Edward Harvey Jeremiah Brown	Machinery for forging or rolling metal
1836	7117	Charles Schafhautl	Apparatus for puddling iron
1836	7142	John Isaac Hawkins	Manufacturing iron (by a process of cementation)
1836	7195	George Crane	Manufacture of iron (use of anthracite and hot blast)
1836	7209	John Ruthven	Formation of rails for railways
1837	7272	Henry Adcock	Construction of furnaces for the reduction of iron and other metallic ores (use of natural draught)
1837	7380	Charles Joseph Freeman	Rolls for rolling rails and bars
1837	7448	Edouard Francois Joseph Duclos	Manufacturing iron (cast iron into malleable iron)
1837	7502	Samuel Mills	Machinery for rolling metals
1837	7518	William Neale Clay	Manufacture of iron (the working of rich ores)
1838	7578	Michael Wheelwright Ivison	Applying air, heated or cold, to blasting or smelting furnaces
1838	7590	Thomas Evans	Rails for railways, and fastening down same
1838	7625	Samuel Wagstaff Smith	Regulating the heat of furnaces for smelting iron
1838	7666	James Hardy	Manufacture of shafts, rails, tyre iron, etc. and rolling machinery therefor

1838	7693	William Gossage	Manufacture of iron (use of hammer slag in the puddling furnace)
1838	7727	William Barnett	Manufacture of iron (coal gas injection at the tuyeres)
1838	7762	Charles Bourjot	Manufacture of iron (making cast iron malleable)
1838	7778	Richard Bradley William Burrows Joseph Hall	Making iron (processing tap cinder for use in the puddling furnace)
1838	7828	Charles Sanderson	Process of melting iron ores (melting the slag without melting the metal)
1838	7888	John Player jnr.	Furnaces for consuming anthracite and other fuel for smelting and heating iron and other metals
1839	8021	Josiah Marshall Heath	Manufacture of iron (without the use of fluxes)
1839	8074	James Vardy	Rolling iron, partly round and partly angular bar
1839	8128	Joseph Jennings	Obtaining metal from pyrites
1839	8206	John Augustus Tulk	Manufacture of iron (smelting hematite ores with silica)
1840	8366	John Whitehouse	Preparing and rolling spoon iron
1840	8389	Gerard Rolston	Improvements in rolling puddle balls or other masses of iron
1840	8459	William Neale Clay	Manufacture of iron (puddling practice)
1840	8479	Samuel Marlow Banks	Manufacture of iron (powdered coke, ore, limestone, etc. injected at the tuyeres)
1840	8518	Josiah John Guest Thomas Evans	Manufacture of iron and other metals (steam forced upon iron in the puddling furnace)
1840	8723	Robert Roberts	Case hardening iron
1841	8820	Charles Schafhautl Edward Oliver John Manly	Puddling or balling furnace to use anthracite as fuel
1841	8855	Thomas William Booker	Manufacture of iron (cast iron into wrought iron)
1841	8935	Lancelot Powell Robert Ellis	Manufacture of iron (boiling)
1841	8959	James Gregory William Green	Manufacture of iron (immersing cast iron in water)
1841	9008	Moses Poole	Producing and applying heat (use of blast-furnace gas)
1841	9017	George Onions	Wheels and rails for railways cast from Lancashire or Cumberland ore
1841	9151	George Allarton	Balling and blooming iron
1842	9298	Sydney Jessop	Preparing wrought iron (for wheel tyres etc.)
1842	9373	Louis Nicolas de Meckenheim	Manufacture of iron (use of waste gases)
1842	9382	James Nasmyth	Machinery for forging iron
1842	9430	Jules Lejeune	Improvements in accelerating combustion, and in place of blowing machines
1842	9495	James Palmer Budd	Manufacture of iron (use of anthracite with cold blast)
1842	9496	William Longmaid	Treating ores and minerals to obtain oxide of iron (from pyrites)
1842	9568	Joseph Beaman	Manufacture of malleable iron
1843	9617	George Benjamin Thorneycroft	Furnaces for the manufacture of iron
1843	9664	Angier March Perkins	Manufacture of iron (use of steam in place of hot blast)
1843	9849	William Danniell	Rolling iron into plates or sheets
1843	9850	James Nasmyth	Improvements partly applicable to forging metals and other substances
1843	9899	John George Bodmer	Manufacturing or working iron

1843	9911	Julius Adolph Detmold	Puddling furnace improvements
1843	9995	Thomas Murray Gladstone	Machines for cutting or shearing iron
1843	9996	George Benjamin Thorneycroft	Rotary squeezer
1844	10038	Thomas Southall Charles Crudgington	Manufacture of iron (the addition of sulphur and a nitrate)
1844	10158	John Dixon	Heating air for blast furnaces
1844	10204	Charles Low	Manufacture of iron (use of admixtures)
1844	10233	Thomas Lever Rushton	Manufacture of iron (puddling furnace additions)
1844	10236	Rees Davies	Manufacture of iron (using an ignited charge for the blast furnace)
1844	10399	John Spencer	Manufacturing iron or other plates for roofing or other purposes (corrugated sheets)
1845	10470	John James Osborne	Furnaces for the manufacture of iron and steel
1845	10475	James Palmer Budd	Manufacture of iron (heating air for blast furnaces)
1845	10651	Charles Attwood	Manufacture of iron
1845	10831	Charles Hodgson Horsfall	Manufacture of iron
1845	10859	Edmund Morewood George Rogers	Manufacture of iron into sheets, plates, etc.
1845	10971	Moses Poole	Hindering the oxidation of cast iron, steel, and malleable iron and rendering malleable iron hard and more durable
1846	11047	William Vincent Wennington	Cutting plate and sheet iron
1846	11067	George Hinton Bovill	Manufacture of iron (heating air for blast furnaces)
1846	11078	James Palmer Budd	Manufacture of iron (use of clinkers)
1846	11322	Thomas Payne	Manufacture of rolls for rolling iron and other metals
1846	11411	John Condie	Machinery used in manufacturing malleable iron
1846	11476	Edmund Morewood George Rogers	Manufacture of iron into sheets, plates, etc.
1846	11482	James Yates	Improvements in the construction of blast furnaces
1847	11598	Charles Fox	Welding metal, and pressing and forming it into shapes
1847	11653	Patrick Moir Crane	Manufacture of iron (use of anthracite in the refinery)
1847	11721	George Benjamin Thorneycroft	Manufacturing rails for railways
1847	11723	Reginald James Blewitt	Manufacture of malleable iron (by using an ordinary foundry furnace)
1847	11738	William Darling	The moulding and manufacture of cast iron articles
1847	11759	William Vickers	Manufacture of iron (running molten iron through water)
1847	11781	Jeremiah Brown	Rolls and machinery used in the manufacture of iron
1847	11810	Moses Poole	Manufacture of cast metal, iron, and steel
1847	11823	George Witherell	Manufacture of iron for various purposes (shafts, etc.)
1847	11906	Alfred Vincent Newton	Machinery for blooming iron
1847	11916	Richard Shaw	Manufacturing wrought iron rails and railway chairs
1847	11970	William Rocke	Treating and applying wrought iron
1847	11971	Alexander Parkes	Manufacture of metals, and the coating of iron and steel

1848	12047	William Russell	Preparing bar iron used in the manufacture of rod iron
1848	12074	James Nasmyth Hallbrook Gaskell	Machinery for forging iron
1848	12087	George Lloyd	Blowing machines
1848	12128	Charles Attwood	Manufacture of iron (ore preparation)
1848	12186	William Hunt	Apparatus for making metals (in the puddling furnace)
1848	12193	William Hunt	Obtaining metals and other products from compounds containing metals
1848	12234	Samuel Lees	Manufacturing malleable iron
1848	12249	Richard Shaw	Manufacture of iron (into bars)
1848	12288	John Davie Morries Stirling	Manufacture of iron (improvements in malleable iron)
1848	12306	John Hairs	Founding type and casting in metal
1848	12323	Richard Coad	Construction of blast and other furnaces
1848	12345	Edward Schunck	Manufacture of malleable iron (use of tin-plate scrap)
1848	12373	William Clay	Machinery for rolling iron
1848	12374	Joseph Deeley	Ovens and furnaces
1849	12416	George Williams	Preparing puddling furnaces
1849	12418	Richard Dugdale	Hardening articles of iron
1849	12457	Lawrence Hill jnr.	Manufacture of iron (working puddlers' balls)
1849	12508	James Baird	Manufacture of iron (heating the blast)
1849	12672	George Benjamin Thorneycroft	Manufacturing tyres, axles and other iron of great strength and ductility
1849	12687	Francis Charles Knowles	Production and manufacture of iron (a direct process of making malleable iron from the ore)
1849	12694	Henry Brown	Rolls for rolling flat and half round pile iron
1849	12706	Reuben Plant	Making bar or wrought iron (regulating the heat of the puddling chamber)
1849	12722	Benjamin Thompson	Manufacture of iron (by withdrawing gases from the furnace)
1849	12750	Thomas Symes Prideaux	Puddling and other furnaces
1849	12793	Charles Attwood	Manufacture of iron
1849	12861	Charles Cowper	Piling, faggoting, and forging iron
1849	12895	Alfred Dalton	Reverberatory and other furnaces (admission of air to the fuel)
1850	12928	Andrew Barclay	Manufacture or working of iron
1850	13001	Thomas Irving Hill	Use of a flux and oxygen in iron smelting
1850	13008	William Joseph Horsfall Thomas James	Rolling iron (especially tyres)
1850	13130	Thomas Deakin	Manufacture of hollow railway lines, and tubes
1850	13140	Robert Heath Richard Handley Thomas	Manufacture of iron (puddled ball to blooms)
1850	13245	Andrew Barclay	Manufacture or working of iron (method of blowing blast furnaces)
1850	13262	Henry Houldsworth	Manufacture of iron, and other metals (use of waste gases)
1850	13265	Charles Harratt	Rolling iron (piling)
1850	13271	William Baggett William Smith	Use of carburetted hydrogen in the blast
1850	13303	Matthew Hodgkinson	Furnaces or apparatus for smelting ores and minerals, and for making pig iron

Coke ovens at Gregory Spring Colliery, Mirfield, Yorkshire

J.R.M.LYNE

At the suggestion of Mr F.W. Smith, Dewsbury Borough Librarian, the Wheelwright Archaeological Society carried out excavations at the above site (Nat. Grid Ref. SE 209 191) between 1968 and 1970. Our object was to establish the structural nature and condition of the ovens, and to try to ascertain the span of their working life by archaeological methods as no written records of any kind appear to survive.[1]

The battery of eight ovens examined lay conveniently close both to the Calder and Hebble Navigation (open 1770) and to Mirfield railway junction (open 1840), giving easy access to major industrial centres in the West Riding and beyond. They may have formed part of a larger complex, locally understood to have lain to the west of the present site, in an area now levelled. However, the excavations produced no evidence to suggest that there had ever been more ovens closely related to this particular group.

As the ovens varied considerably, both in their state of preservation and in detail, they have been treated separately in the following account. The numbers are those of the plan (Fig. 1).

Oven 1, the most southerly, was found to be substantially intact. It consisted of a roughly hemispherical dome constructed of tapered refractory bricks on a level, solid brick floor.[2] The internal diameter of this dome at oven floor level was 7ft 3in (2.2m). Flue size could not be assessed, as the top few courses of brick were missing. The inner face of the brickwork was heavily coated with a hard dark-brown or black bituminous deposit, but the incrustation was appreciably lighter near the floor, and the floor itself was free of it.

The exterior of the structure was wholly enclosed in a continuous bank, which had similarly covered the domes of the other ovens to flue height. Built against the east side of the line of ovens, and serving to retain this bank, was a much robbed stone wall faced in ashlar, laid dry. In this, giving access to the domes at floor level, had been the arched openings of the oven doors. The width of the only complete surviving example - that of oven 1 (Plate I) - was 2ft 6in (76cm), as was its height from the sill iron to the head of the arch. A single mortice cut in the stonework on each side of the arch, level with the point of spring, suggested the position of rings for holding the bar on which rakes would be rested during levelling.[3] One such ring survived in oven 2.

Excavation was undertaken (see plan) to recover details of construction.

It was found that the natural ground slope had been faced back, and a brick floor laid on the levelled clay below the vertical cut (section A-B). The oven dome had then been constructed on this floor, the space between the structure and the cut face of the slope being filled with a loose rubble of broken brick, clinker, and stone. The south side of the oven had been protected by a single-brick retaining wall set back against the excavated clay face and the space between this and the dome had been similarly filled with rubble.

It seemed probable that at least the rear infilling of the stone wall containing the oven door had been built after the dome, as backing stones overlay the brickwork.

Excavation in front of the oven door produced rubble from the facing wall and a few bricks from the dome, four small post-holes, and two shallow pits partly defined by an irregular area of consolidated ash. All the above features were associated with pottery identical to that contained by the debris in the oven itself, and were clearly late. Beneath these lay two distinct layers of ash and cinder, the lower of which rested directly upon the levelled surface of the natural clay. Towards the eastern baulk, away from the oven, the higher ash layer tapered out against an area of mixed clay. The lower layer continued beneath this. Again, all pottery related to the abandonment of the oven.

Oven 2 was clearly of the same structural pattern, and of one build with oven 1. The door arch in the facing wall was largely destroyed, but the spring-stone survived on the south side, still retaining an iron ring-bolt at a point corresponding to the mortice holes noticed previously in oven 1. In the case of this oven also, the junction of the brick dome with the stone facing wall suggested that the dome was built before the back of the facing wall was finished.

The original flue was here preserved. The circular central opening, approximately 1ft (30cm) in diameter, had been boxed round with a square of brickwork to support the muffling plate, and a brick in situ bore the stamp "Jos. Cliff: Wortley" (Plate II).

Excavation in front of this oven produced a picture very similar to that found before oven 1. A hard patch of trodden ash was again noticed on the north side of the door arch at a high level, though here a small area of mixed paving in brick and stone had been laid above part of it. The two distinct layers of dark ash and cinder were also present, separated this time by a layer of fine red ash close to the oven. This latter resembled ash present with the rubble between the oven dome and the facing wall.

Oven 3, though poorly preserved (Plate III), could be seen to differ in certain respects from ovens 1 and 2, from which it was separated by a single dry-brick wall similar to the one marking the present south end of the battery. Although the door arch was completely demolished, the sill stone had survived, and it was notable that a deep, sloping chamfer seen in the centre of the sills of ovens 1 and 2 was here entirely absent, suggesting a different method of closing the oven. Further, angle-irons had been set in the brickwork of the oven floor at both inside

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MAX LYNE is a master at the Wheelwright Grammar School, Dewsbury, Yorks.

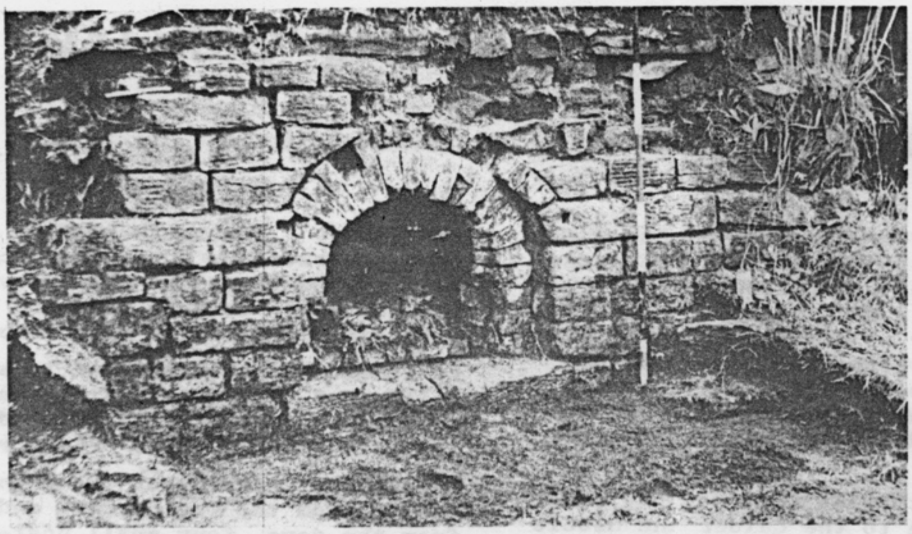


Plate I Door of oven 1 Photo. F.W.Smith

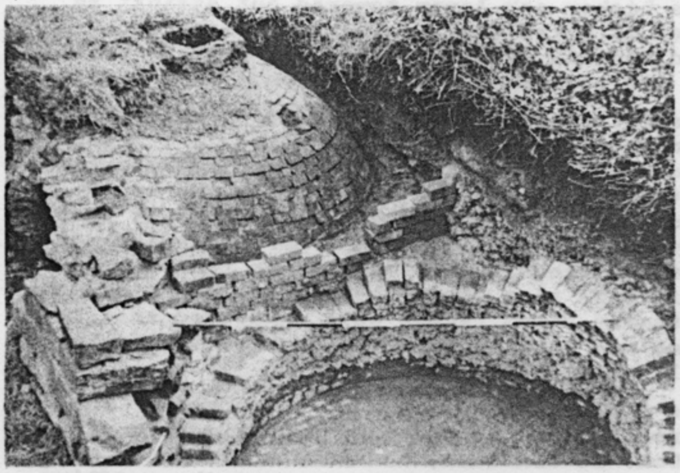


Plate II Oven 2 (background) and oven 3 (foreground)

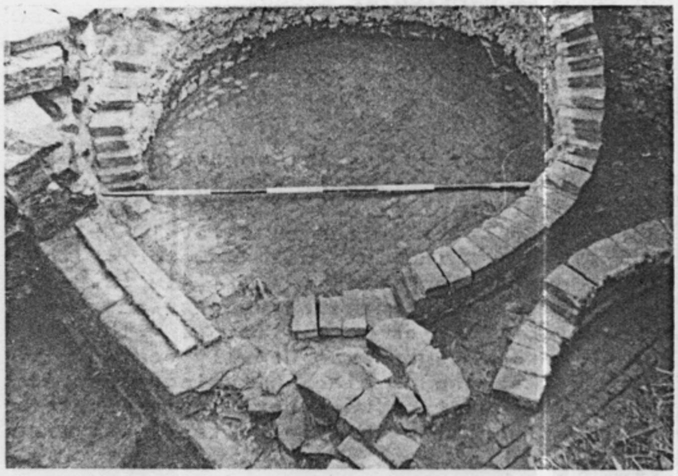


Plate III Oven 3

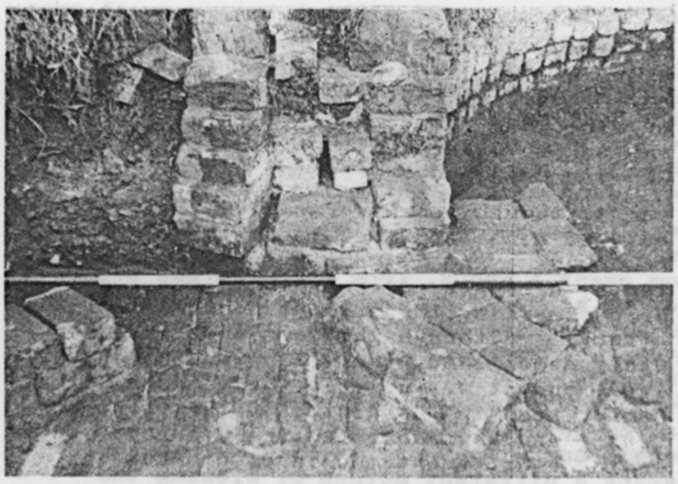


Plate IV Junction between ovens 7 and 8, showing continuity of brick platform

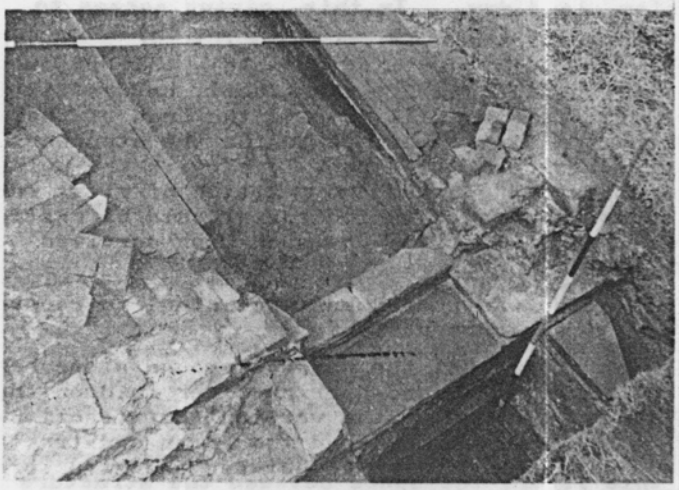


Plate V Section through floor of oven 8

ALL SCALES IN FEET

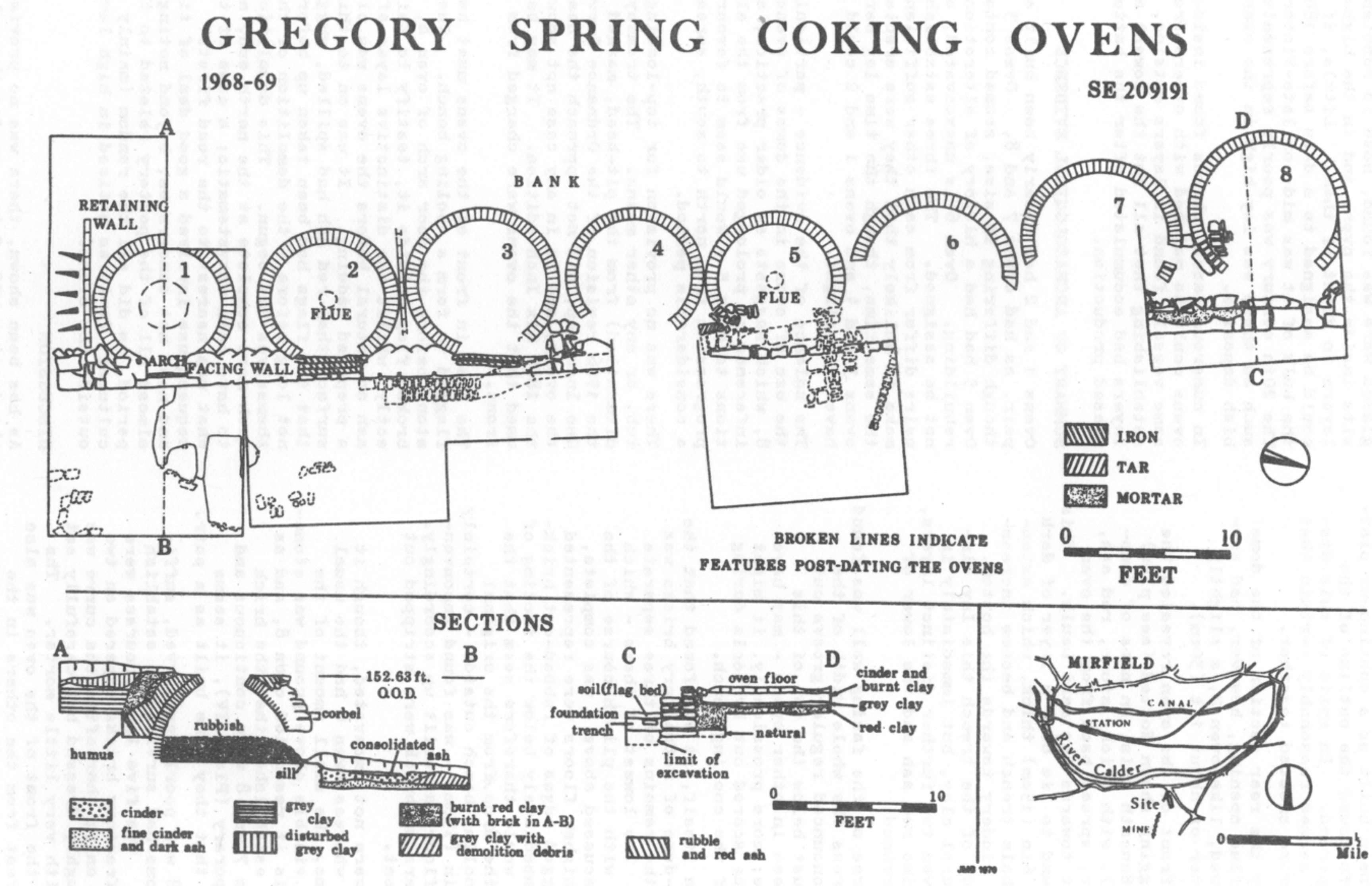


Fig. 1 Plan, sections, and location of site (Location Map derived from the Ordnance Survey Map of 1888)

corners of the door arch - the stump of one of these was found in place - to protect the masonry from damage during raking. This feature was not observed elsewhere.

Oven 4 was not fully excavated. However, its relationship with oven 3 was examined, and it was found that the brick floors of the two ovens had not been built as a continuous platform, but had followed the outline of the ovens they supported. In spite of this discontinuity, it seemed reasonably certain that ovens 3 and 4 were erected together.

Oven 5 had only the rear section of the dome intact. The flue opening, however, had survived, and showed, like oven 2, a slightly variable diameter of about 1ft (30cm).

Excavation in front of the oven revealed the pattern of flagging shown dotted (see plan) in topsoil. Beneath this, an area of demolition material, with brick, stone, red ash, and lime mortar, spread back from the oven and tapered out towards the east baulk. This was in turn found to lie over a layer of dark ashy soil some 6in (15cm) thick, which extended over the whole trench and became increasingly hard and cindery towards the bottom. At the east side of the trench this lay directly upon natural clay, but immediately in front of the oven two further distinct layers, the upper of fine red ash and the lower of dark ash, intervened.

The lowest course of the facing wall was found in position across the whole width of the trench. A pronounced regular groove cut horizontally just below the top of this course - not seen in other ovens - may have been decorative; more prosaically, it might represent a line scored out by tools during the clearing of the cooling bench.

Within the oven itself, it was found that the surviving half-dome of refractory bricks was standing upon the remains of three separate brick floors. The lowest of these - which finished flush with the plinth course of the facing wall discussed above - was complete, while the two higher floors were represented only by the ragged edges of robbed-out brickwork visible immediately below the footing of the dome. It would therefore seem that the slightness of the drop from the original floor to the cooling bench outside - certainly no more than 6in (15cm) - was found inconvenient, and the floor was built up accordingly. The higher layers of brick were stripped out after abandonment.

Ovens 6 and 7 were not excavated, though it was noted that whereas oven 6 had the usual brick-built dome, the small amount of the dome of oven 7 visible above ground was stone-built. In this it resembled oven 8, and as it was further established that the brick floors of ovens 7 and 8 were continuous and clearly contemporary (Plate IV), it seems safe to assume that they were built as a pair.

Although oven 8 was poorly preserved, sufficient of the dome had survived to establish its structure. The five lower courses were composed of refractory bricks tapered on two opposite sides only; thereafter the curve was obtained by roughly dressed but carefully set stones, laid with very little mortar. The arrangement at the front of the oven was also markedly different from the others in the range, in that the stone facing wall had been neatly recessed to admit a substantial flagstone immediately below the door arch. A second (broken) flag lay at the same height in front of the facing wall, and was bedded on a layer of ashy soil which extended over the whole area seen at this point.

A section through the oven floor showed it to consist of a single thickness of brick, laid on a mixture of fine ash and cinder over the levelled natural clay (Plate V).

THE POTTERY

A large quantity of screen-printed and other glazed ware was found, both in rubbish deposits inside the ovens and in the higher ash layers in front of them. Little, if any, could be assigned to a date before 1800, and the bulk of it was mid- or late-Victorian. The 20th century was poorly represented, and such as there was lay high in the oven rubbish deposits.

In numerous cases, sherds found inside the ovens could be matched with others from the same vessels found in layers outside, thereby establishing that all but the lowest ash layers had accumulated after the battery had ceased production.

SUMMARY OF ARCHAEOLOGICAL EVIDENCE

Ovens 1 and 2 had clearly been built as a pair, as had ovens 7 and 8. Ovens 3 and 4, though differing in size, seemed contemporary. Oven 5 had had a history of alteration and rebuilding. Oven 6 is unexcavated, and cannot be assigned. The three established pairs differ from each other sufficiently to make it unlikely that they were erected at the same time, though the time lag between ovens 3 and 4 and ovens 1 and 2 could well have been slight.

The balance of the evidence - particularly the use of stone in the domes of ovens 7 and 8, which suggests an older practice, and the inference of prolonged use from the alterations to oven 5 - would seem to favour a progression from north to south, spread over a considerable period.

There was no provision for top-loading by tub, or any other means. The tramway (now dismantled) from the pit-head, marked on the 1966 revision of the Ordnance Survey One Inch Map, did not approach the head of the ovens, and is in any case not shown on the 1888 Six Inch edition. It may be assumed that the ovens were charged from the front.

The area in front of the ovens must have been flagged to form a cooling bench. The flagstone before the door arch of oven 8, and the broken flag outside it, testify to this directly, whilst the distinctive layer of fine ash on natural before the ovens was clearly a prepared bedding. It was on to this surface that red ash had spilled, suggesting that the flags had been taken up before - but not long before - the demolition of the ovens themselves had begun. This demolition was much more complete at the north end, and seems to have been unsystematic; a case of taking what was nearest to the road first. Subsequent use involved a good deal of tipping, and need not concern us, beyond noting that almost all of the pottery related to this period, as did all the random (mainly agricultural) features noticed in high levels outside the ovens.

DISCUSSION

As has been shown, there was no provision for the drawing-off of tar, or for the collection of any other by-product. From this lack of sophistication it is tempting to infer early dates both for the construction and the abandonment of the plant, but such an inference would be unsafe. Although the possibility of collecting the many by-products of the coking process had been understood at least since the Earl of Dundonald's success at Culross and elsewhere in the 1780s,[4] it was commonly held into the last decade of the 19th century that by-product recovery ovens yielded less satisfactory coke than the simple internally heated beehive.[5] The strong demand for high-grade metallurgical coke, stimulated after 1835 by the vast railway construction programme's appetite for iron and steel, tended to prolong the profitability of what was basically a slow and wasteful method. Direct sales of coke to the railway companies as locomotive fuel, until the switch to coal firing in the 1870s, would also help to keep demand and prices up. It was not until the depressed economic conditions experienced towards the end of the century, which affected coal and steel along with most other major industries, that the combination of rising wages and sluggish capital return[6] would make the oldest and least efficient beehives look unattractive. Even after 1871, the then newly formed Mirfield Colliery Company (a grouping of coal-owners not, it seems, including the proprietor of Gregory Spring) found it worthwhile to build and operate a battery of 20 beehive ovens at their Dark Lane pit.[7]

In the 1890s, significant numbers of British coal-owners began to follow the lead of their more progressive opposite numbers of the Continent, and installed recovery ovens. However, it was still possible in 1904 for an engineering consultant[8] to state that more than half the metallurgical coke (which he totalled at about 50 million tons for that year) was produced in non-recovery beehives, and to growl indignantly that "The work of the pioneers of the Coke Oven Industry has not been taken up by those who ought to have done so, not owing to a want of mental capacity, but to a kind of mental lethargy, which dislikes all innovations. Foreign engineers have taken up what English engineers had neglected ...."

There can be no automatic presumption, therefore, of early closure. However, the treatment of the ovens in the Ordnance Survey map of 1888 suggests that they were then derelict and it marks a small enclosure immediately in front of ovens 1 and 2, which may well explain the areas of consolidated ash and the stake holes recorded there as post-abandonment features.

As regards the date of construction, we have the statement of R.A. Mott (quoting Parkes : "Chemical Catechism", 1808), that the first beehive ovens in Yorkshire were erected near Sheffield in 1802, and the cross-section he publishes bears some resemblance to the Gregory Spring pattern. This, then, would seem to offer a satisfactory terminus post for ovens 7 and 8. There is also reason to assume ovens 1 and 2 later than 1842, the date of the first appearance of the brick-yard proprietor "Jos. Cliff: Wortley" in the Leeds directories.[9]

Within these very imprecise limits perhaps a little cautious speculation may be permissible.

Ovens 7 and 8 - and perhaps the first phase of oven 5 - would seem to fit most comfortably between 1820 and 1835, before, one assumes, the general availability of suitably shaped refractory bricks to build the domes, but after the local market for metallurgical coke had begun to expand, and the canal had established easy transport. Increased output (represented by the addition of ovens 1 to 4) would logically be encouraged by the growth of the local railway network in the 1840s, with the possibility of sales of locomotive coke to Mirfield Junction, just across the river, and could have proved profitable at any time up to the early 1870s. Thereafter, it would become economically less and less defensible, particularly in the face of competition from the new Dark Lane battery nearby. The decision to discontinue could not have been taken much after 1880, and may well have been earlier.

This was a small, basic plant, which could only have been successful in most favourable conditions; but even though a very minor prop in the Victorian industrial scene, it perhaps deserves a passing glance.

NOTES AND REFERENCES

1. The writer would like to take the opportunity to thank all the many people who have assisted in this enquiry. Mr E. Hoyle, Area Director for the National Coal Board, Mr C. Brooke and Mr J. Pearson, successive managers of Shuttle Eye Colliery, and Mr R. Hindby, tenant of the land on which the ovens stand, have all been most helpful and courteous. Mr D.W. Crossley, of the Department of Economic History, University of Sheffield, Mr F.W. Smith, of Dewsbury Museum, and Mrs Hilary Brook, his assistant, have also given much time and encouragement to us. Of my fellow members in the Society I shall only say that it is they, by their enthusiasm and hard work, who have made this report possible; Mr J.M. Bayne's drawing records the extent of their activities.
2. In the interests of clarity, the brickwork of the floors is not shown in the plan; it may be assumed in all the ovens.
3. For a fuller description of the levelling process, and a useful summary of the working of beehive ovens in general, see B. McCall : "Beehive Coke Ovens at Whinfield, County Durham", <u>Industrial Archaeology</u>, 1971, <u>8</u>, No. 1, Feb.
4. R.A. Mott : "History of Coke Making", 38 : Cambridge, 1936.
5. Ibid., 76 et seq.
6. S.B. Saul : "The Myth of the Great Depression", 32-3 : London, 1969.
7. H.N. Pobjoy : "History of Mirfield", 188 : Ridings, 1969.
8. P.J. Mallman : "Coke Ovens and Their History" (Paper read to the Cleveland Institution of Engineers, Middlesbrough, April 1904).
9. This firm had been trading as firebrick makers at least since 1817, under John Cliff. Joseph Cliff took over in 1842, and was apparently still in business in 1881. The firm has since been absorbed by the Leeds Fireclay Company.
10. References to the early history of coke making appear in J.C. Carr and W. Taplin : "History of the British Steel Industry", 53-55, 133-4, and 210 : Oxford, 1962.

Metallurgical examination of a Roman iron beam from Catterick Bridge, Yorkshire

J.H.WRIGHT

Editorial Note

The beam was excavated at the Roman settlement at Catterick Bridge, Yorks., by J.S. Wacher in 1959. Details of the dating, the site, and the environment in which the beam was found will be described in a separate monograph, to be published by the Department of the Environment.

A discussion of the function and use of composite blooms of this nature appears in a paper by J.S. Wacher entitled "Roman Iron Beams" (Britannia, 1971, 2, 200-202).

The following report deals with the metallurgical examination.

APPEARANCE OF THE SPECIMEN AS RECEIVED

The beam was covered with a layer of earth and oxides of various colour shades, ranging from light yellow to dark red. The numbered and arrowed points on Fig. 1 show where five different samples of the surface covering were taken for analysis (given in Table I).

DIMENSIONS AND WEIGHT

The gross weight of the beam as-received was 2 cwt 2 qtrs 17 lb (135kg), including the surface coating. After the whole of the surface encrustation had been removed, the net weight of the metallic beam was 2 cwt 2 qtrs 2 lb (128kg), which means that 15 lb of surface coating was removed.

Figure 2 is a photograph showing the external appearance of the beam after removal of the surface coating, and Fig. 3 is a cross sectional sketch giving dimensions.

ANALYSIS OF SURFACE COATING

Table I gives analytical results of the surface samples taken at the five points shown in Fig. 1.

Sample 1 appears to be a general corrosion product or deposit, consisting of rust and clay.

Sample 2 is a mixture of "limestone" and impure iron oxide in about equal proportions.

Sample 3 resembles iron-bearing sandstone.

Sample 4 is evidently a furnace product or cinder, consisting largely of silica and ferric oxide.

Sample 5 is a hematite-rich area of low sulphur content.

EXAMINATION OF THE METALLIC PORTION OF THE BEAM

After surface examination, the beam was sectioned longitudinally by machine cutting, and in this operation some difficulty was experienced owing to the softness of the metal and the occurrence of internal cavities.

Sulphur Print

A sulphur print was obtained from the whole of the longitudinal cross-section in the usual way, by pressing acidulated silver bromide paper into contact with the cleaned and polished metal surface. Figure 4 is a photographic copy of the sulphur print thus obtained.

Macro-Etching

Figure 5 shows the appearance of the polished section after etching with ammonium persulphate solution. This clearly indicates that the beam is made up of several portions of metal, which have been welded together. For the purpose of later identification, these separate portions are numbered from 1 to 17 on Fig. 5, and the outline of each portion or area has been emphasised by the use of black ink.

Each area indicated in Fig. 5 was drilled for analysis, the drillings separated from slag, and analyses made of the metal.

Analytical Results

Table II gives the analytical results obtained from each of the 17 metal samples, and in this table the last column includes the silica content, which arises from non-metallic or slag contamination.

The drillings from area 1 at the top of the beam were grossly contaminated with a black powder, which was recovered by suitable methods and analysed separately. The black powder gave an analysis of 46.56% FeO, 46.29% Fe_2O_3, indicating that it is largely magnetic oxide of iron Fe_3O_4.

Hardness of Metal Exposed by Sectioning

Table III gives the results of hardness determinations carried out on three of the areas shown in Fig. 5, together with approximate equivalent tensile strengths. There is a wide variation in each area, owing to the heterogeneity in composition. The last hardness result in Table III is from a portion of area 15, which was heat-treated by normalizing from 900°C. It will be noticed that this form of heat treatment does not remove the variations in hardness previously observed.

Micro-examination

Numerous non-metallic inclusions were present, consisting mainly of oxides and silicates, as would be expected. Figure 6 is a photomicrograph, suitably etched, taken from area 10, towards the middle or bottom of the bloom. The carbon content at this point was found to be 0.14%. The photomicrograph shows ferrite grains of rather large size (ASTM 2-3), suggesting that this area was finished at high temperature, probably about 1200°C or more.

Figure 7 is a photomicrograph taken from area

The late J.H. Wright was chief metallurgist with Dorman Long (Steel Ltd at the Central Research Department, Newport Iron Works, Middlesbrough, until his death. This company now forms part of the British Steel Corporation.

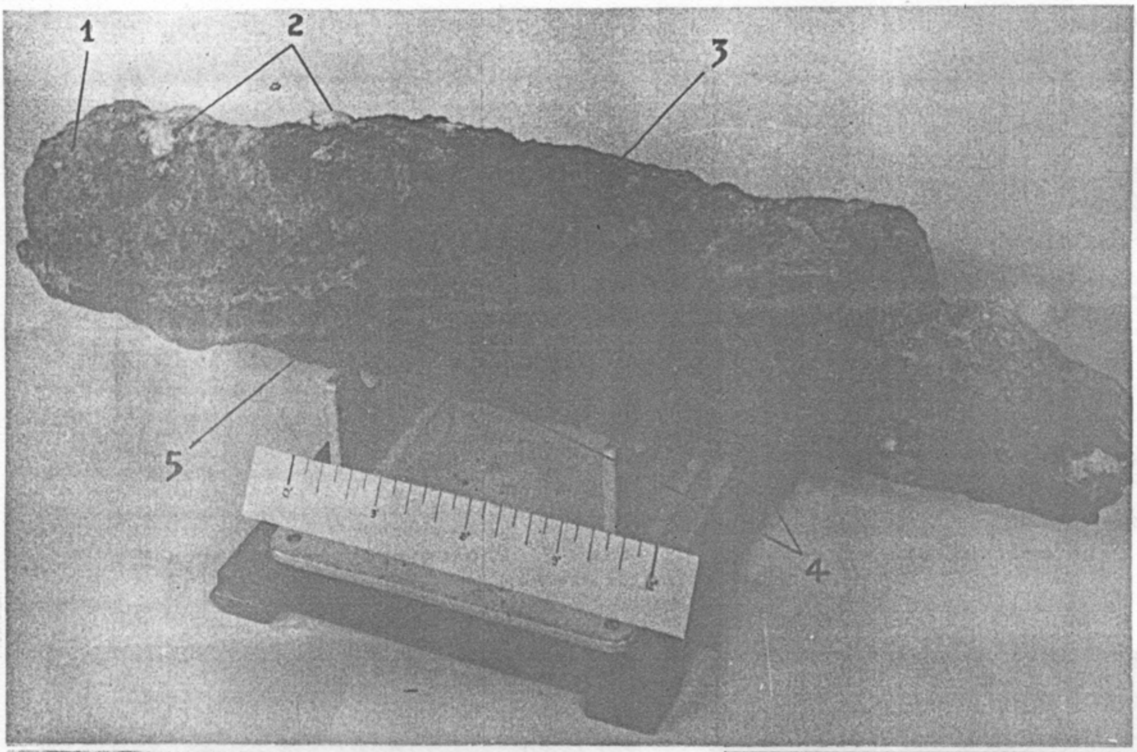


Fig. 1
Beam as-received
(Scale : inches)

Fig. 2 External appearance of beam after cleaning

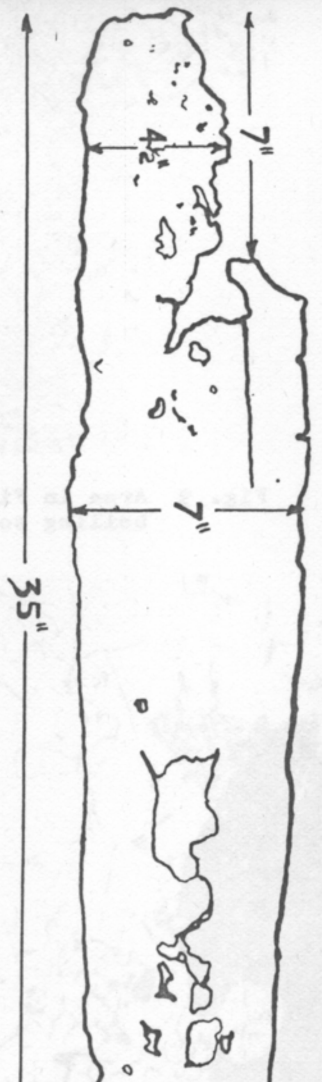


Fig. 3 Cross-section of beam with dimensions

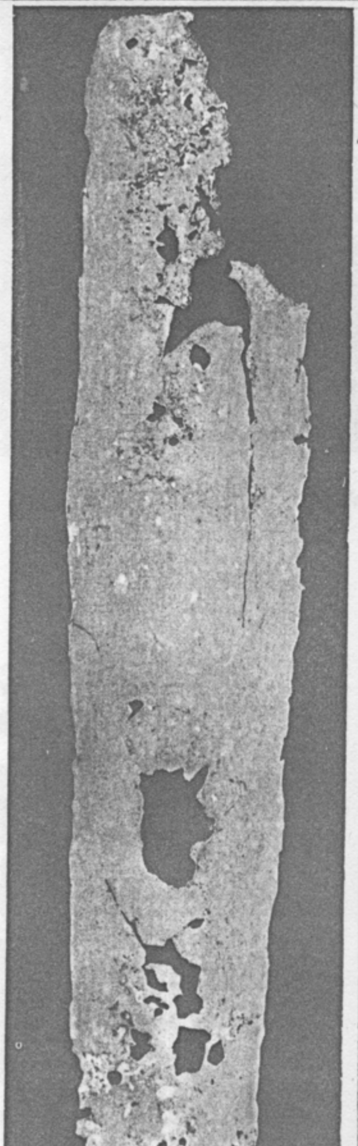


Fig. 4 Sulphur print

Fig. 5 Polished section after etching

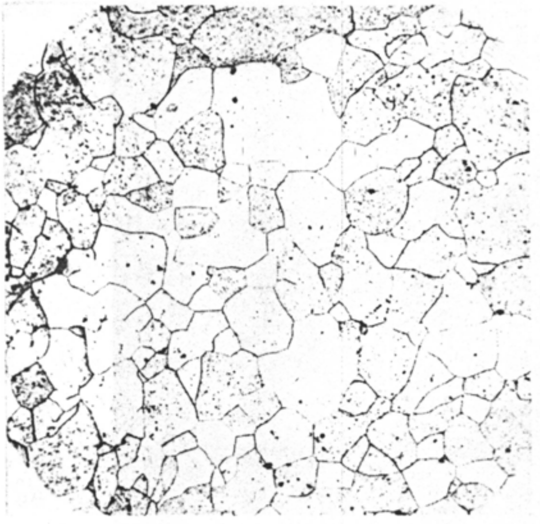


Fig. 6 Photomicrograph of area 10 x 42

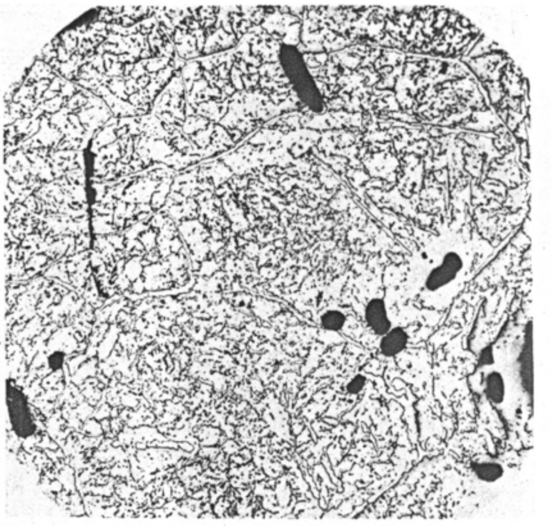


Fig. 7 Photomicrograph of area 3 x 42

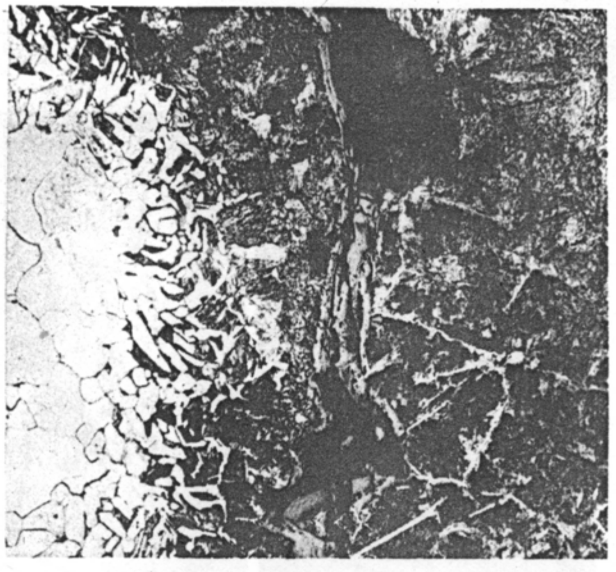


Fig. 8 Photomicrograph of weld junction between areas 10 and 12 x 42

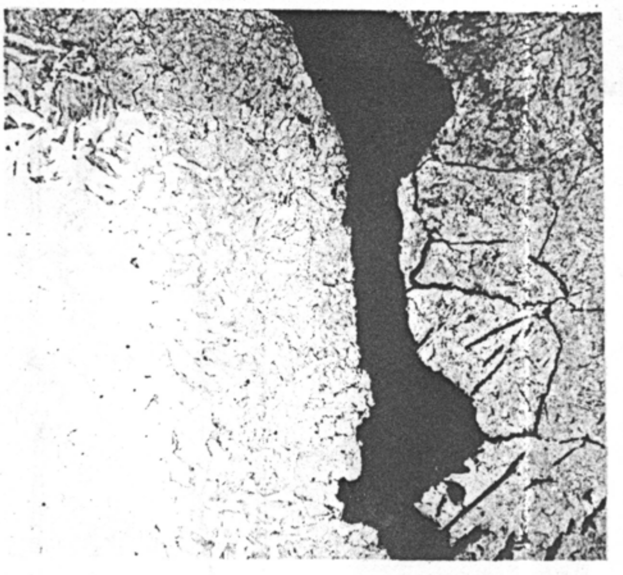


Fig. 9 Area in Fig. 8 after etching in boiling sodium picrate x 42

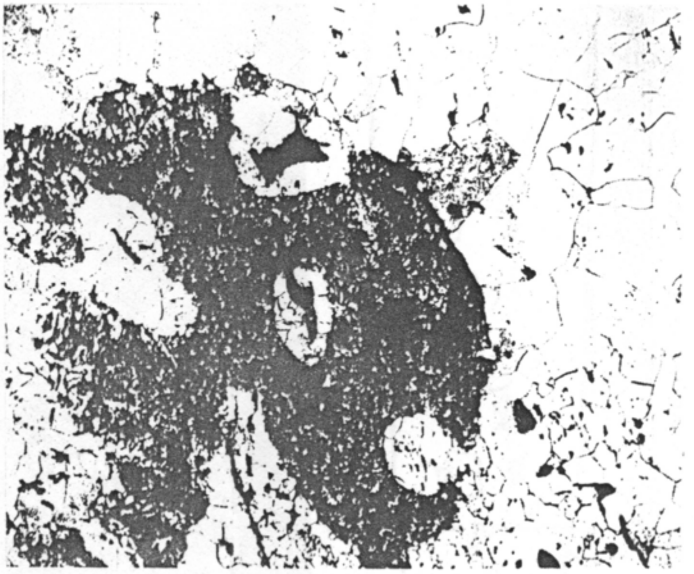


Fig. 10 Photomicrograph of area 15 x 25

3, at the top of the beam. The carbon content at this point was 0.64%, and the microstructure includes spheroidized carbides, which are evidently the result of a prolonged period at a temperature of about 680°C.

Figure 8 is a photomicrograph of a weld junction between areas 10 and 12. At the weld junction, there is a massive slag inclusion, and on the right-hand side of it lines of cementite are shown as a white network against a background of pearlite.

Figure 9 is the same area and specimen as shown in Fig. 8, after etching in boiling alkaline sodium picrate. This reagent has blackened the white cementite network shown in Fig. 8.

Figure 10 is a photomicrograph taken from area 15, towards the bottom of the beam. This shows a carbon-rich area (dark) immediately adjacent to a low-carbon area (white network) after being normalized in the laboratory at 900°C.

DISCUSSION OF RESULTS

This ancient iron beam can be classified as a porous mass of wrought iron, built up of several small pieces, which have been welded together. The smaller pieces of wrought iron were evidently produced by a reduction process direct from the ore. The low sulphur content of the iron suggests that charcoal was used as the fuel during reduction, refining, and welding processes.

The beam is in many respects identical with that reported by Sir Hugh Bell (JISI, 1912, 85, (1), 118-129). It shows the same features of manufacture, similar porosity, inclusions, and variations in carbon content in the metal.

For welding the beam, no doubt the same type of furnace or forge was used as that described and illustrated on pp. 124 and 125 of the paper by Bell.

TABLE I Analyses on dried material, wt-%

Sample No. in Fig. 1	1 General corrosion deposit	2 White shell-like encrustation	3 Yellow-coloured deposit	4 Cinder-like deposit	5 Red-coloured deposit
Silica	10.82	4.56	41.38	20.20	5.78
Ferric oxide	61.71	12.86	37.43	51.40	81.43
Ferrous oxide	10.88	18.51	1.16	4.76	2.20
Alumina	2.26	1.83	1.24	3.92	1.20
Manganese oxide	--	--	0.20	--	0.20
Lime	2.20	26.00	1.80	0.74	3.10
Magnesia	0.58	0.57	0.47	1.38	0.40
Phosphorus pentoxide	0.78	0.34	2.40	1.85	0.82
Sulphur	0.03	0.13	0.02	0.04	0.02
Sulphur trixide	0.27	0.14	--	--	--
Carbon dioxide	4.90	26.40	--	--	--
Combined water	5.14	8.70	--	--	--
Loss on heating to red heat	--	--	13.54	15.26	4.54
Total Fe	51.62	23.40	27.1	39.70	58.71

-- = not determined
nd = not detected

TABLE II Analyses on metal samples, wt-%

Area No.	C	Mn	Si	S	P	SiO_2
1	0.50	nil	nd	0.040	nd	nd
2	0.15	"	"	0.016	"	"
3	0.64	"	"	0.028	"	"
4	0.10	"	0.024	0.028	0.099	0.140
5	0.20	"	0.028	0.030	0.092	0.085
6	0.04	"	nil	0.024	0.137	0.011
7	0.04	"	"	0.020	0.068	0.170
8	0.04	"	0.028	0.015	0.077	0.110
9	0.03	"	nil	0.010	0.074	0.025
10	0.14	"	0.020	0.013	0.062	0.088
11	0.03	"	0.005	0.015	0.065	0.024
12	0.02	"	--	0.010	0.068	nd
13	0.02	"	0.039	0.010	0.054	0.068
14	0.26	"	0.110	0.012	nd	nd
15	0.03	"	nd	0.012	0.047	"
16	0.04	"	"	0.022	0.087	"
17	0.06	"	"	0.020	0.071	0.136
Average	0.138	--	0.025	0.019	0.077	0.086

Drillings were taken in the 17 areas shown on Fig. 5.

TABLE III Hardness of metal exposed by sectioning

Area No.	Hardness HV	Approx. tensile strength, tons/in^2
5	98.4-135	18.6-31.1
10	82-162	15.0-37.0
15	78.5-155	14.2-35.9
15 normalized at 900°C	78-147	14.2-33.6

Ironmaking by the bloomery process at Nornäs, Sweden, in 1851

J.A.W.BUSCH

Editorial Note

This description was published as an appendix to the book by Severin Solders, "Alvadens Sockens Historia, Pt. III. Myrjärn - Hemsmide - Liebruk", which was published in Stockholm in 1946. It was thought worth translating into English because of the current interest in the mechanism of the bloomery process and its detailed step-by-step treatment. The process may be compared with that described by Ole Evenstad for Norway and published in Bull. Hist. Met. Group, 1968, 2, (2), 61-65.

We are grateful to Dr Inga Serning for supplying the original and for arranging to have the original Swedish units converted into their modern equivalents. We have to thank J.P. Tylecote and Mrs Hedberg for the translation.

IRON-MAKING IN NORNÄS, 1851

(From the College of Mines archives, letters, and papers, supplementary series 1830-1857)

Minutes

Concerning measurements taken, and concerning other noteworthy things at Fänjäsbläståan, situated in the parish of Särna, next to the border with Elfdalen and Nornäs village, as well as about the iron-smelting which took place there on 6th August 1851 and, further, about the forging at a bar-iron hearth near Avesta, of the blooms obtained from the 3rd smelt and also about the forging of them, and about the testing of the resulting iron bars at the manufacturing forge at the last named place on the 21st of the above-mentioned month and year.[1]

PART 1

The upper part of the furnace, or the "pipe", had almost the shape of a distorted and inverted cone 12 inches[2] in height and 1 fathom top diameter; but its lower part or the stand itself was built in one piece with the upper part, in a parallelepiped shape 20 inches long (between the tuyere-wall and the blowing-wall), 18 inches wide and 18 inches deep. The small departures from a conical shape were of course at the transition from the stand's rectangular shape to the round shape of the pipe. The stand was made of granular limestone. It did not have a slag tapping hole.

The tuyere was circular and of forged iron; its inside diameter, at the opening, was 7/8 inch; its taper to the bottom $\frac{1}{4}$ inch over its whole length, which was 12 inches; the height of the inner lower edge above the bottom, $4\frac{1}{2}$ inches; the projection (in the stand) in front of the tuyere-wall, $2\frac{1}{2}$ inches; but originally, before the tuyere was burnt off, this dimension had been $3\frac{1}{2}$ inches.

The bellows consisted of two wooden boxes in parallelepiped shape about 3 square feet in cross-sectional area and an 18 inch high remainder, which for the time being, owing to the shortness of the lifting pole, was not more than 11 inches. Driving power came from a 5 foot breast-waterwheel, to the shaft of which two cords were fastened. Most of the water was brought in from two springs, the water of which was so warm that even in the most severe winter it almost never freezes at the dam. The tools were : spit, hook, fire pan, shovel, wooden rake, and tongs.

PART 2

Time Hrs	Min	**The first smelt. Smelter : Hård Lars Ersson in Nornäs**
A.M. 10	45	The furnace was filled with rather dry, knotless seasoned wood, cut in 1 to 2 decimal square inches cross-sectional area. The wood was set up in the bottom of the furnace, in a cone shape with the point downwards, but, from the middle of the furnace, it was put in horizontal layers, and that continued up to a height of 2 to 3 spans on top of the upper edge of the furnace. The wood was lit at the bottom without blast.
11	00	The flame was visible on top.
	07	Started to lay a little ring of charcoal round the edges and continued with that for 5 minutes, according to how the charring of the wood was progressing. The total addition of charcoal amounted to just about half a barrel.
	23	First, thin layer of ore[3] added round the edges, after which the charcoal was thereby compressed and the wood inside lifted somewhat so that the charring was speeded up. Further, a about 3 minute intervals, more ore was placed on the top of the charcoal pile, as the wood up there became more and more charred.
	30	Began gentle blowing, as almost all the wood on top was charred, even if some in the middle was to some extent still uncharred.
	42	Blast increased.
	45	Charring of the wood inside was now also completely satisfactory. Just about half a shovel, approximately 1/6 of a peck, of ore was put over the hole pile whenever the coals were getting bare, or the ore had sunk between them, and that was about every 3rd minute. Between every addition the charcoal was packed down with a wooden rake.
	50	An air vent hole was pierced through the middle of the charcoal pile.
	55	Blast further increased.

11 58 P.M. Middle hole pierced again.

12 01 The last shovel of ore was put on, and now the total ore addition consisted of one pail 10.7 decimal inches diameter and 9.5 decimal inches deep, of a better sort, and one shovel of just about half a peck, of a worse sort. Before the beginning of blowing both sorts were carefully cleansed of stone, well mixed and intimately blended with each other.

09 The blast was increased again. Compressing of the charcoal continued frequently, although no more ore was being added. When the hole in the middle became too big, and when the blast tried to escape more on one side than the other, charcoal was scraped out from one place to another, as required.

20 A handful of stove ash was taken, of which 1/6th or 1/8th was put in the middle of the pile "to encourage the smelting".

42 Three pinches of ash were put on for the last time, and with that about half of the original quantity had been used. The adding of these ashes had been carried out approximately every 5 minutes.

45 The charcoal surface had become level with the upper edge of the rectangular portion; and when adding the charcoal it could be seen how the pieces were somewhat stuck to each other by the melting ore.

58 Small charcoal was scraped away from above the tuyere down to its level and a large firm piece placed there instead, to encourage the deflection of the blast towards the opposite wall.

1 00 Sparks of burning iron began to be thrown up by the blast, and this then increased more and more.

03 The ore from both walls to the sides of the blast stream was pushed back towards it, and this operation was afterwards repeated every second or third minute.

05 Two double handfuls of charcoal were put on above the tuyere.

11 A few pinches of ash were put on again.

16 A double handful of charcoal was put on. The slag was now seen to be flowing quickly with white grains of iron in it.

19 The blast was slowed down and it was

20 turned off. The finished bloom was picked up and hammered all round, and found to weigh 17 pounds victual weight,[4] to be soft and to have only a thin layer of slag around it. The slag was picked up afterwards as well as small pieces which contained iron, ore and slag, caused by the cold walls.

The second smelt. Smelter : Hård Lars Ersson in Normås

1 30 The furnace was filled with wood of the type previously mentioned; and the flame was now visible almost immediately.

1 45 The ring of charcoal was put on. The ore was blended from one pailful and one shovelful of better ore and one shovelful of poorer ore. (The pail contained 5 shovelsful.)

2 00 The first ore was put on. Subsequent additions, as well as the charcoal packing, now proceeded as previously described.

12 The blast was started and

25 then increased, just as all the wood became charred. The first ore addition was the largest (about one whole shovelful) in order to extinguish the large wide ring of coals, so that they should not burn up to no purpose. Later, as the pile of coals got smaller, the ore additions were then also reduced down to 1/3rd or 1/4th of a shovelful.

43 Finished adding ore and simultaneously increased the blast. Ashes were now added, as during the first blowing, in small portions, but this time more, or almost two handfuls, were used. When the blowing was half completed, the pile of coals was kept highest above the tuyere, "to secure a stronger heat towards the opposite wall."

3 50 After scraping off, the large coal was placed above the tuyere.

59 The iron sparks started to burn, and then, as during the first smelt, a double handful of coals was put on above the tuyere.

4 05 Again the same amount of charcoal was added above the tuyere "to encourage the heat towards the opposite wall."

08 Blast stopped, because the machine broke down, but it was started again. Meanwhile, the slag had flowed into the tuyere, so that

23 the blowing had to be stopped completely and the bloom taken out. In spite of considerable loss of iron on this occasion, the bloom registered 18 pounds victual weight. While it was still red it was hacked into two pieces with an axe, in 4 minutes.

The third smelt. Smelter : Hård Lars Ersson in Normås

5 15 The furnace was filled with wood. The ore was blended in the same way as at the 2nd smelt. When all the wood had become black or charred at the surface and just when the flame over the whole furnace was largest

25 the usual measure of charcoal was put on around the edges, "so that the charcoal would be glowing well by the time part of the wood becomes completely charred." Later when the charcoal was fully aglow, and empty spaces started to show round the edge, the coals were broken and the wood, with some interruptions, lifted up, so as to give better air for its combustion. Afterwards the coals were packed carefully against

40 the outer edge again, and the first ore addition was made. The additions and packing-downs then continued as usual, until the white flame emerged from no more than 1/4th of the surface of the pile, and that just from the very top part.

6 00 When the combustion was sufficiently advanced, the blast was turned on. The machine's wheel shaft made only 7 revolutions per minute to begin with; but, when all the sticks were

10 charred, the blast was increased to 8 revolutions per minute of the wheel and after that it was increased every 5 minutes, until the wheel,

20 as ore addition was complete, reached a speed of 10 revolutions per minute and finally,

25 at the last increase of blast, a speed of 11 revolutions per minute. After completing the ore addition the ash additions were started, and the scraping together, in a similar way to what took place during the 2nd smelt. This time a hole appeared by itself through the middle of the pile, so no piercing was required.

7 25 Raking off above the tuyere took place and the larger coals were put there.

30 New coal was put on.

45 Two double handfuls of coals were put on, to cover the broken pieces of ore from the sides, that were melting.

50 Again a large coal was placed above the tuyere.

8 00 The bloom was hacked into two parts, weighing together 23 pounds victual weight. This bloom was bought for the account of the Royal College of Mines, and later forged to bar-iron, which is now kept in the Royal College of Mines Mineral Cabinet.

The fourth smelt. Smelter : The prospector and blast furnace foreman P. Petterssen

8 20 Started to fill the furnace with wood. With regard to quality, quantity, and blending, the ore was the same as that used for the 3rd smelt, and the quantity of charcoal was also just the same as it was during the previous smelts.

35 The charcoal was put on.

50 The first ore addition was made.

9 00 Started the blast, which began to be increased after 10 minutes, with further increase every 5 minutes after that.

15 The flame stopped.

35 The last ore addition was made, and at the same time the blast was increased for the last time. The speed of the bellows wheel then reached the same maximum as before, 11 revolutions per minute.

10 40 Pierced the hole in the middle; then, for the first time, some pinches of ashes were put on, and this was repeated every 3-5 minutes. The packings down were carried out carefully. Once again charcoal was added at the end, in the same way and with the same amount as during the 3rd smelt.

50 The bloom was taken out and hacked in two. Its weight was 25 pounds victual weight. It was bought for the account of the Royal College of Mines and is now kept in its Mineral Cabinet.

Remarks

1. A suitable ore blend is needed so as to prevent too much iron from getting into the slag; this had been, according to Hard Lars Ersson, the most difficult thing to discover.

2. The reason why twigs and heartwood must not be used in the bloomery furnace was that "that kind of wood burns too long with a white flame and the coals finally created from it get too hard; the other type of coal produces the right effect simultaneously."

3. The parallelepiped shaped charcoal measure at Fänjäsblästan, the dimensions of which were 1.51ft x 1.27ft x 1.46ft, contained 2.766 cubic feet[5] or 27$\frac{3}{5}$ cans. Now, if the two handfuls of charcoal added towards the end of the smelt are counted too then one finds that the charcoal consumption was just about 28 cans or ½ barrel, for each smelt.

4. The wood was sawn, with special waterwheel power, into log-ends 3, 4, 5, and 6 spans long, so that the lengths would suit the different dimensions of the furnace. A log of 7 to 8 inches diameter and 7 to 8 cubits length was used up at each 3 hour blowing.

5. The work with the bloomery furnace can be handled by a smelter and one assistant, the latter's most important work being to cut wood, but if the smelting, as planned, is to continue night and day, there must be at least two smelters, who replace each other after each completing their shift of three smelts. The assistant, on the other hand who, during each blowing, should have the chance to sleep at least half the time, might possibly be able, alone, to serve both the smelters.

6. In order to get a comparison between the quantity of iron produced from the ore in a bloomery furnace and in a blast furnace, the following details may be useful :

According to information from the prospector and blast-furnace foreman P. Petterson, at the blast furnace at Paulström, in the Kalmar region, it was normal to put on 1100 pounds rock weight[6] of lake and marsh ore at each addition and, as well as this, 20 charcoal additions of 9 barrels each, every 24 hours, from which about 9½ ships pounds pig-iron[7] weight of iron was obtained.

Therefore, 22,000 pounds rock weight of ore produced about 4860 pounds rock weight of iron. But, as a heaped half-peck of clean-washed ore was found to weigh 14 pounds victual weight, it follows that a barrel would weigh 14 x 32 = 448 pounds victual weight, or 448 x (2500/2210) = 507 pounds rock weight; so that 22,000/507 or 34.5 barrels of ore produce 4860 pounds rock weight of pig iron.

By comparison, the ore smelted at Fänjäsblästan, comprising 1$^{1}/_{5}$ pails of better grade and $^{1}/_{5}$ pail of poorer grade, gave 25 pounds victual weight or (5.250/4.221) x 20 = 28 pounds rock weight of workable iron. Now the diameter of the pail was 1.07 feet and its depth 0.95 feet, so its volume was 0.885 cubic feet, and if the amounts are now added, then the quantity of better-grade ore becomes 0.855 x 1$^{1}/_{5}$ = 1.026 cubic feet, and of the poorer grade = 0.171 cubic feet, and the total quantity of ore = 1.197, or almost 1.2

cubic feet, which is 12 cans or 12/56 = 0.214 barrels. So now we have 0.214 barrels of roasted ore giving 28 pounds rock weight of bloom, so that, from the relationship 0.214/28 is as 1/x, one finds that 1 barrel of blended ore, cleansed by roasting, gives 28/0.214 = 130 pounds rock weight of bloom. The comparison between the results at the Paulström blast furnace and the Fänjäsblastan bloomery furnace therefore becomes as follows :

1 barrel of lake and marsh ore, cleansed by washing, produced at Paulström, 112 pounds rock weight of pig-iron

1 barrel of blended marsh ore, cleansed by roasting, produced at Fänjäsblästan, 130 pounds rock weight of bloom.

PART 3

Both the blooms produced at the 3rd smelt, which, according to the weights inspector in Nornäs, together weighed 23 pounds victual weight, weighed no more than 21 pounds victual weight on arrival at Avesta. Wear and tear due to the severe shaking on the post-chaise during the 30 league journey, together with some possible differences in the scales, even if both were crowned, could perhaps have caused this difference in weight.

The forging of the large piece, which weighed 11 pounds, in the bar-iron hearth, by a smith who was not used to that type of iron, was taken much too hard (white heat instead of light red, as urged by Mines Inspector Öngren) with the result that this piece broke into three at the first blow under the bar-iron hammer. However, the bits were gathered up, carefully beaten together, and then again several times with great care, which finally resulted in an iron bar of 7½ pounds which, hardened, with grey-blue stripes on the surface, showed a steel-like nature.

The bar withstood many blows on the edge before it broke and the fracture was seen to be mostly crystalline but also, to a small extent, at one edge, somewhat stringy.

From this bar some horseshoe nails were then forged, which were so soft that, in spite of the fact that the point was bent cold about 20 times to and fro, it still did not break off, but only split near the tip, as a result of the previously mentioned unevenness of the iron.

The smaller bloom of about 10 pounds was not heated so hard as the larger one; it was also turned more often in front of the blast. The consequence was that this bloom did not break under the hammer, and it produced a bar of exactly the same weight - 7½ pounds victual weight - as that from the larger bloom.

The quality of the iron was equal in both bars.

Even if the loss from the latter bloom was a whole pound less than from the former, it might, with a smith who was used to such iron, have been even less, and then if one also remembers what dropped into the hearth, one can see that longer experience with the same materials and, finally, with the larger blooms of the future, would have provided an important replacement for the loss in weight suffered, so that one finds that the loss in this particular case was not of any special significance.

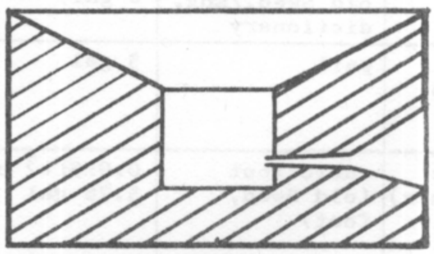
The reason that Hård Lars Ersson and Fider Lars Ersson in Nornäs again took up iron manufacture was that Langö Mill had started again in the 1840s and they were keen on having bog iron for their scythe manufacture. The method had been described to them by their fathers. At Langö they had made attempts to smelt bog ore in a bar-iron hearth but failed completely. Both these Nornäs men then got the necessary iron equipment from the mill, which also promised to buy all that they could produce at a price of 8 Riksdollar banco per ship's pound victual weight (170 kg), delivered at the mill (6 leagues away from Nornäs). In addition to this, they were able to sell to Horrmunds Mill, which lay considerably nearer and was owned by Varg Hans Ersson in Lövnäs.

How long Fänjäs bloomery was in use is not known. Probably the work was stopped fairly soon. Nevertheless, bog ore smelting was taken up again at the same place on one further occasion, namely by Fider Anders Petterson, in the 1870s.

(Compare an article by H. Carlborg in <u>Blad för bergshanterings vänner</u> (Paper for Friends of ironworking), No. 17, 1922, 99 et seq.)

Notes and References

1. These minutes cannot, of course, include other than what I saw with my own eyes. If questions arise concerning a description of bloomery furnaces in general, with the relevant ores and working methods etc., then the best sources of information on these subjects can be obtained partly from <u>Jernkontorets Annaler</u>, XXIX, Volume 1, and partly from "A Short Description of Methods for Smelting Lake and Marsh Ore in Bloomery Furnaces", printed by Johan A. Carlbohm, Stockholm, 1794.
2. Here the word "inch" always means working inch (24.742mm) when the word decimal is not mentioned. The decimal inch = 29.69 mm. (Translator)
3. The ore, taken from Björnadalen and from Nornäs, was cold-roasted without having been cleansed of earth, sand and tree-roots by previous washing. The cold roasting procedure was said to have been carried out by placing alternate layers of wood and ore.
4. Victual weight (v.v.) = 17 scale pounds = 7.225kg. 1 tt v.v. = 0.425kg. 1 tt rock weight (b.v.) = 0.376kg. (Translator)
5. The arithmetic is wrong; it should be 2.8 cubic feet. (Translator)
6. (55 lispund b.v.) b.v. = rock weight = 55 lispund b.v. = 413.6kg. 1 L tt b.v. = 7.52kg. 1 L tt v.v. (victual weight) = 8.5kg. (Translator)
7. Ship's pound = 196kg. (Editor)



Section through Swedish bloomery hearth
Top part circular, bottom part rectangular

NOTES ON LENGTH, VOLUME, AND WEIGHT DIMENSIONS

Swedish Text	Literal Translation	Current English Equivalent	Current Metric Equivalent	Comparison with Hand-written Swedish notes on Original Text	Other Remarks
tum werktum	inch	0.973in	24.74mm	Page III says = 1/12 fot = 24.74 mm	Checked as correct by visit to library. Old Swedish inches and feet definitely shorter than English one
dec. tum	decimal inch (1/10 old Swedish foot)	1.168in	29.69mm	Page III says = 29.69 mm	
qvarter (6 werktum)	span (from old Swed./Eng. dictionary)	5.84in	148.5mm	Page IV says 2 to 3 qvarter = 0.3 to 0.5 m, i.e. qvarter = 150mm	OED gives span as 9in but visit to library confirms "kvarter" = 6 old Swedish inches
fot (12 werk-tum or 10 dec. tum)	foot	11.68in	296.9mm	Page III says 10 dec. tum = 296.9mm	Checked as correct at library
aln (4 qvarter or 2 fot)	cubit (from old Swed./Eng. dictionary)	23.36in	594mm	Page VIII says 7 to 8 alnar = 4 to 5 m, i.e. aln = between 570 and 625 mm	OED gives cubit as 18in but library confirms aln = 2 old Swed. feet or 24 old Swed. inches
famn (6 fot or 3 alnar)	fathom (from old Swed./Eng. dictionary)	5ft 10in	1782mm	Page III gives this as 1.8m	Fathom is 6ft but library confirms famn = 3 aln, i.e. 6 old Swed. feet
mil (18,000 alnar)	league (from old Swed./Eng. dictionary)	6.64 mils	10.689km	Page IX gives 3 mil = 320 km, i.e. 1 mil = 10.66km Page X gives 6 mil = 65km (i.e. mil = 10.84km)	OED says league is "about 3 miles" (5 km) but modern Swed. mil = 10km, and library confirms old Swedish mil = 36,000 old Swed. feet, i.e. 10,689 m
njupor	pinch				
näfve	handful	$\frac{3}{4}$ pint	0.43 litres		Page VII (Remark 3) indicates 2 handfuls = $\frac{1}{3}$ can, i.e. handful = 1/6 can = $\frac{3}{4}$ pint
kann	can	4.57 pints	2.60 litres	Page VIII says $27\frac{2}{3}$ kannor = 72.4 litres and 28 kannor = 73.3 litres. Page IX says 12 kannor = 31.37 litres, i.e. 1 kann = 2.62 litres	Page VIII of the text says 28 kannor = $\frac{1}{2}$ tunna and Page IX says 56 kannor = 1 tunna. Library confirms kann = 2.60 litres and 7 kannor = 4 kappe (see below)
kappe (& skofvel)	half-peck (and shovel-ful) from old Swed./Eng. dictionary	1 gal (from OED : 1 peck = 2 gal)	4.55 litres	Page IV says $\frac{1}{3}$ kappe = about 1.5 litres & "just about 1 kappe" = 4.5 litres	Confirmed at visit to library, which also showed that 4 kappe = 7 kannor
ämbare (5 kappe)	pail	5 gal	22.7 litres	Page IV gives calcul-ated 22.5 litres from dimensions of pail in text	Page V confirms in text by saying 1 ämbare holds 5 skof-vel (i.e. kappe)
kub. fot (10 kannor)	cubic-foot (old Swed. foot)	0.925ft^3 or 5.76 gal	36.0 litres	Page IX gives 0.855 kub.fot = 22.4 litres, i.e. 1 kub.fot = 26.2 litres	Based on old Swed. foot (see above). Library confirms & says = 10 kannor
tunna (32 kappe or 56 kannor)	barrel	32 gal	145.47 litres	Page IV says "just about $\frac{1}{2}$ barrel" = 70 litres. Page IX says 1 tunna = 150 litres	Page IX confirms in text by saying 56 kannor = 1 tunna, i.e. 145.47 litres. Also confirmed at library

Swedish Text	Literal Translation	Current English Equivalent	Current Metric Equivalent	Comparison with Hand-written Swedish Notes of Original Text	Other Remarks
tt pund skalpund	pound "bowl" pound scale pound				
L lispund	20 pounds				
tt v.v. pund viktual-itevikt	pounds victual weight	0.936lb	0.425kg		Stated in printed footnote, Page V
L tt v.v. lispund viktual-itevikt	20 pounds victual weight	18.72lb	8.5kg		Stated in printed footnote, Page VIII
tt b.v. pund bergs-vikt	pounds rock weight	0.78lb	0.376kg		Stated in printed footnote, Page V
L tt b.v. lispund bergsvikt	20 pounds rock weight	16.58lb	7.52kg		Stated in printed footnote, Page VIII
Sk tt tack-jernsvikt Skeppund tackjerns vikt (26 lispund bergsvikt)	Ship's pound, pig-iron weight	428.8lb	194.5kg (according to library but 26 x 7.52 = 195.6kg)	Page IX says 9½ ship's pounds pig-iron weight = 1860kg	Text (Pages VIII/IX) says 9½ ship's pounds pig-iron weight is equivalent to 243 lispund rock weight, i.e. about right

Extraordinary General Meeting, 25 September 1971

Minutes of an Extraordinary General Meeting held on the occasion of the Annual Conference at Devonshire Hall, University of Leeds, at 7.45 p.m. on Saturday, 25 September 1971.

Apologies for absence were received from Messrs J. Angus and J.W. Butler and from Professor H. O'Neill.

Minutes of the A.G.M. 1971 having been published in the Bulletin, Vol. 5, No. 2, p. 79, these were taken as read and signed as a correct record, apart from an error in line 7, which should read "Bulletin, Vol. 4, No. 2."

There were no matters arising.

The Chairman explained that the meeting had been called to discuss problems that had arisen during the summer. The Iron and Steel Institute had informed the Group that it had been forced as an economy measure to withdraw all financial support from the Bulletin, amounting to about £700 per annum. Thus the Group now needed to be self-sufficient, and its present level of income put the frequency and format of the Bulletin at risk.

He assured the meeting that the Committee were making every effort to economize on the costs of administration, and to find ways of producing the Bulletin more cheaply, but it seemed unlikely that more than one issue of a simplified version would be feasible in 1972. He gave notice that, even on this basis, an increase in subscription to £1.50 might well be necessary in 1973 but that the situation would be reviewed finally at the time of the 1972 A.G.M.

He proposed, and the Treasurer seconded, a motion that a category of Family Membership, at £1.50, should be instituted for 1972. This was passed without dissent.

The Treasurer drew Members' attention to the regrettably large number of subscriptions that were overdue, currently totalling about 100, and he also asked those present to do what they could to recruit the new members upon whom the continued viability of the Group depended.

In the discussion that followed, the Committee was urged to consider the level of Conference fees, differential Conference payments for Members, Family Members, and non-Members, the need for further advertising of the Group's activities, and membership on special terms for students and for student societies.

The Chairman promised that all these points would be discussed, and expressed his appreciation that they had been made. He asked that anyone with further ideas for ensuring the continued existence of the Group on a more sound footing should communicate with the Secretary.

There being no further business, this Extraordinary General Meeting was declared closed at 8.25 p.m.

A metallurgical examination of some objects from Marlik, Iran

R.F.TYLECOTE

The burial mound at Marlik was excavated recently by Dr Ezat O. Negahban, Director of the Archaeological Institute of the University of Teheran, and his team. The site lies at the south-west tip of the Caspian Sea, near Udbar in the valley of the Gohar Rud.

Over 50 tombs, varying in size and structure, were opened, indicating that the cemetery had been used over a long period from about 1300 BC to the Ist millennium BC. The grave goods consisted of a rich assembly of gold and silver objects, bronze vessels, weapons and tools, as well as pottery, jewellery and a great variety of ceremonial objects, such as figurines of deer and mountain goats.

In the absence of stratification the dating is based mainly on a comparison with similar objects of the neighbouring cultures, which clearly shows links with the Talish region and areas north and south of the Zagros mountains.

We have no historical information about this culture; its position probably saved it from Assyrian raids. It is nevertheless clear that the people buried in this mound were warrior chieftains who enjoyed a considerable amount of prosperity and were able to acquire the beautiful and precious metal objects either by exchange for agricultural products or cattle, or as gifts or booty from other areas. Whilst the overall influence of Near Eastern art, especially that of Assyria and Urartu, can be traced in the fine execution and style of the gold objects, some might well have been made in local workshops. Professor Negahban reports the finding of bronze tools and ingots, which might indicate the burial of a smith. The presence of an iron punch here might be of significance. A similar punch was found at the cemetery of Tepe Sialk A, together with a dagger dated to c. 1000 BC.

The only other two objects of iron examined below were a dagger blade with a bronze hilt and a spearhead. The scarcity of iron finds clearly shows that the culture was essentially of the Late Bronze Age. The bronze arrowhead with a tin content of 6% is of a type common over a wide area. For example, 3000 bronze arrowheads of 50 different types were found in the tombs, as well as 20 different types of spearhead and 25 different types of dagger in great quantity.

The beginning of the Iron Age I in Iran has recently been dated to about 1300-1000 BC, and the iron objects from Marlik might well belong to the latest phase of this period, i.e. 1000 BC.

Results of the Examination

Dagger hilt XVIIIC This consisted of the hilt end of a tanged iron or steel blade embedded in bronze. A section was cut from the broken end shown in Fig. 1a and it was seen that the ferrous part was lozenge-shaped, as shown in Fig. 1b.

The blade had been made out of a carbon steel containing between 0.1% and 0.2% C. It had been forged in such a way that the few slag inclusions had been elongated in the direction

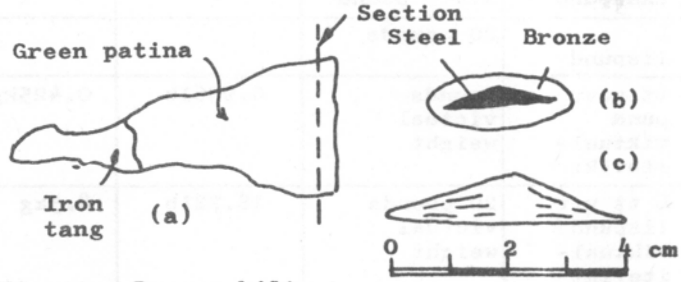


Fig. 1 **Dagger hilt**

of the section of the blade, as shown in Fig. 1c. This indicates that the blade had been widened in the forging operation and no doubt lengthened at the same time. The structure had a very fine grain and consisted mainly of globular carbides in a matrix of ferrite. This indicates that the steel had had a long time in the medium-temperature range 650-750°C, and there is little doubt that a good deal of the final shaping had been done at this temperature. Hardnesses of 160, 206, and 240 HV5 were obtained across the section.

The bronze hilt showed the typical structure of a cast tin bronze containing about 10-12% tin with about 5% or less of lead. There were signs of destannification due to corrosion. The casting had been slowly cooled and the hardness was 100 HV5.

Spearhead XIXk A small piece was removed from the blade near the tip (Fig. 4). Again, this was a steel containing 0.1-0.2% carbon. It contained some slag stringers, but was on the whole a good deal cleaner than the dagger blade. The grain size was very fine and again the carbide was spheroidized. The hardness was 182 HV5.

Rock wedge or punch XXIIIG This was a roughly cylindrical object with one end rounded by hammering and the other apparently broken. A small piece was removed from the latter end. This was a very clean steel indeed, and it was very difficult to find any trace of slag. Most of the section consisted of pure ferrite with grain-boundar carbide and had a hardness of 202 HV5. A small part of the section consisted of ferrite and divorced pearlite with a hardness of 257. These hardnesses are not consistent with iron-carbon alloys, and it is certain that this specimen at least contains a considerable amount of phosphorus.

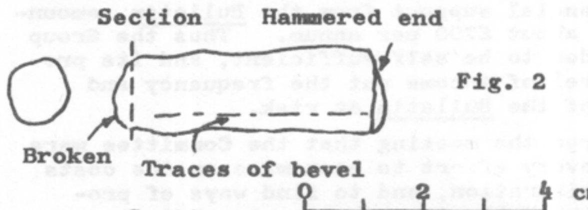


Fig. 2 **Punch**

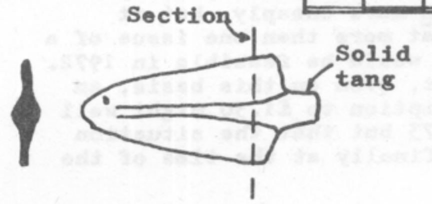


Fig. 3 **Arrow-head**

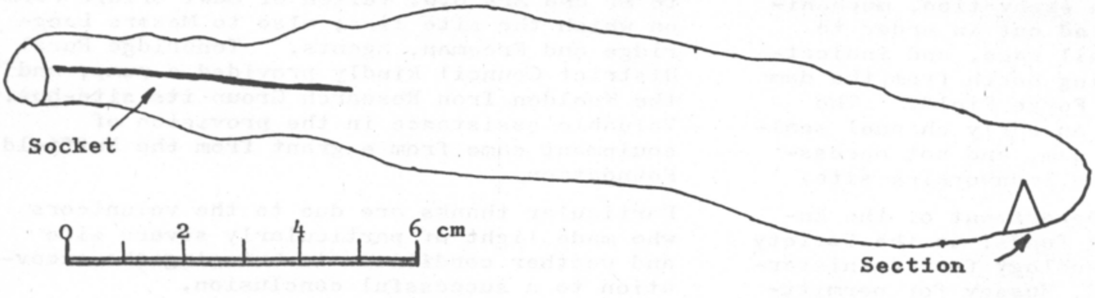


Fig. 4 Spearhead

Non-ferrous strip XXIIIG This contains a good deal of slag but is clearly copper or dilute copper-base alloy. It has a wrought structure but has been annealed since its final working or has only been hot-worked.

Bilobate arrowhead XXIIIG The specimen was sectioned at the position shown in Fig. 3. This object has been made from a casting, but the lobes have been widened by cold working after casting. It is a very nicely made artifact and would have been superior to the later arrowheads cast in bronze moulds. The centre, which shows the original cast structure of bronze, has some degree of shrinkage porosity. The hardness in this region was 70 HV5. Just beyond, at the edge of the lobe, the metal is denser and the hardness increases to 145. The tip of the lobes themselves shows a highly worked structure with twins and deformation markings and have a hardness of 168. It would seem that the object had been heated and hot-worked, followed by localized cold working at the edges of the lobes. The tin content would be about 6%, and neither lead nor zinc are present.

I am indebted to Professor Negahban for allowing me to examine these objects.

Chingley Forge, Kent, 1971

D.W. CROSSLEY

This year excavations were completed at the Forge site (TQ 682 336) and attention will in future be concentrated on the Furnace upstream (TQ 684 327).

In 1970 the Forge site had had to be backfilled with major problems left unanswered. The 16th and 17th century timber wheel races had been excavated, but there were indications that earlier structures lay beneath. A sample of filling had been removed from a narrow race beneath the levels explored in 1970, and fragments of a wheel had been recovered, together with a very limited sample of pottery which included a sherd of stamped Rye ware.

This year the whole of the filling of this early race was excavated, and the timber structures associated with it recorded and dismantled. The silts of the race, the deposits on the working area to the east, and the filling of the tail-race produced finds consistent in period. The coarse pottery of the area has not been thoroughly published but there is little doubt that the unglazed black wares, both cooking pots and jugs, from these layers were of 14th century origin, as were the glazed sherds. Metalwork comprised nails and some non-ferrous scrap; cinder was present, but there was less than might have been expected at a water-powered bloomery.

The timber structure consisted of a massive framework, using mortice, dovetail and half joints; this lay southwards from the dam, and its western half comprised the wheel race. The timbers upon which this lay, and those which bridged it, extended eastwards and had supported massive north-south timbers, probably the base frame for the hammer which the water wheel would have driven. To the north, the tail-race was ill-defined, with only fragments of a timber edging for the first 2m. Thereafter it was merely an ill-defined hollow.

The interpretation of the purpose of the early structure raises certain problems. While the timbers were so massive that a hammer seems the most likely equipment to have been mounted on them, no actual fragments were found which could prove this. Further, the quantity of bloomery cinder was small, and tap-slag in particular was rare. However, while the possibility of the site's use for some other purpose requiring water power, such as fulling or corn milling, cannot be ruled out, the presence of non-ferrous scrap in the race silts must be seen as significant; someone working here was experienced as a smith, and this, taken with the location, close to iron ores, the cinder and the massive structures must suggest an association with metal working. The most likely answer is that the site was a hammer forge for working up blooms of iron produced at the smelting sites (bloomeries) in the area; it is indeed interesting to note in this context that the unpowered smelting site near Withyham, some 10 miles to the east, excavated by J.H. Money, had no hammering plant, and could well have relied upon a local water-powered counterpart of this early period at Chingley. If this were the case at Chingley, no great amount of cinder might be expected, merely the product of the stringhearth used for reheating during hammering.

In addition to the main excavation, mechanical trenching was carried out in order to section the dam, the tail race, and indications of a channel running north from the dam in the central part of Forge Field. The latter was found to be an early channel sealed by the 16th century dam, and not necessarily connected with the ironworking site.

Thanks are due to the Department of the Environment for providing funds; to the Society for Post-Medieval Archaeology for administering the grant; to Mrs C. Hussey for permitting excavation on Scotney Castle estate, and to Mr and Mrs G.D. Veitch of Bewl Bridge Farm on which the site lies; also to Messrs Langridge and Freeman, agents. Tonbridge Rural District Council kindly provided a pump, and the Wealden Iron Research Group its site-hut. Valuable assistance in the provision of equipment came from a grant from the Nuffield Foundation.

Particular thanks are due to the volunteers who made light of particularly severe site and weather conditions in bringing the excavation to a successful conclusion.

Annual Conference in Leeds : Lead mining in Yorkshire

For many years now, the Annual Conference has been the most popular event of the year for the HMG. So it was not surprising that the numbers present this year broke the record and reached over 80. The seat of the Conference was Devonshire Hall, one of the University Halls of Residence, and our host was the Professor of Metallurgy, Jack Nutting.

The proceedings started on Friday night with introductory talks by Dr Arthur Raistrick and Bernard Jennings on the lead mines and their miners, and gave us an inkling of what we were to see on the following day. After breakfast, we piled into two coaches and took off for the Dales with Dr Raistrick, Bernard Jennings, and members of the staff of the Metallurgy Department as our guides. First we visited the sites at Greenhow, then had a picnic lunch at Burnsall, and after went for a long walk over Grassington Moor, where we inspected the smelters and their chimneys.

After returning to Hall, we had dinner, followed by business in the way of an Extraordinary General Meeting. This was quickly got out of the way and an informal discussion on matters of general interest followed.

The scope of the Conference was broadened somewhat on Sunday morning with two contributions on the local iron industry. Mr Ward, formerly of Monkbridge, gave us an interesting talk on some of the ironmaking processes used in the Aire valley, and Mr Edmund Butler followed with a most intriguing and amusing account of the early history of Kirkstall Forge, mostly culled from the diaries of a formidable lady, Betty Beecroft, who was for a long time one of its partners.

The Conference dispersed after lunch; once again we had reached the end of the Group's event-of-the-year. For a long time we shall remember the impressive hospitality of Leeds and the valiant efforts of our hosts, our guides, and our speakers which made it such a success.
(Preprints of Conference papers may still be obtained on application to the Hon. Treasurer)

Dr Arthur Raistrick with members on Grassington Moor

(Photo : Roy Day)

Book Reviews

D. Diderot and J. d'Alembert (Ed.) : Encyclopédie, ou Dictionnaire Raisonné des Sciences, des Arts et des Métiers. Volume of Plates. Readex Microprint Corporation, New York, 1969. 1146 pp. Price £40.00.

Members may like to know that a single volume containing all the plates of this valuable work is now available. The original work of 35 folio volumes has recently been reprinted in Paris and is on sale for about £600. By photographic reproduction it has been found possible to reduce this to five volumes with a shelf-space of only 1ft and a price of £135. Each page measures 15½ x 10 in, and contains four columns of print. While it is possible to read the letterpress and understand most of the detail of the plates with the naked eye, a rectangular lens of 1.5-2 magnification makes this very much easier. The separate volume of plates contains all 3132 plates and their descriptions and is bound in half-leather.

To those who are familiar with the original edition of this famous work there is little to add, but those who have to make short fleeting visits to consult the library copies will appreciate the value of being able to possess such a work. This volume gives many of the facets of mid-18th century life in the greatest detail and the beautiful plates with their accompanying descriptions are a never-ending source of basic technical information. It describes the various types of furnace for non-ferrous metal extraction, blast furnaces, forges, and pin-making machinery, to mention but a few of metallurgical significance.

This volume is available at a price within the reach of a local or departmental library and those individuals who either cannot afford it or who do not feel that it is of sufficient value to their work to buy it might encourage those responsible to get it on the shelves.

R.F. Tylecote

J.G. Rollins : The Needle Mills. Society for the Protection of Ancient Buildings, London, 1970, 16 pp. Price 30p.

A valuable description of the techniques used in needle making from the 16th century to the 1930s, in the Worcestershire-Warwickshire area and the watermills that served the industry. It is well illustrated.

R.F. Tylecote

C.C. Lamberg-Karlovsky : Excavations at Tepe Yahya, 1967-69. Progress Report No. I, Bulletin No. 27 of the American School of Prehistoric Research, Peabody Museum, Harvard. Cambridge, Mass., 1970.

This report gives the archaeological background to the metal artifacts analysed and reported in <u>HMG Bulletin</u>, 1971, <u>5</u>, (1), 37-38. Other metal artifacts were found such as copper-base pins, chisels, awls, and spear-heads of periods dated to 3800-2200 BC, and ironwork of the Sasanian period (after AD 400). These objects have not yet been analysed metallographically.

R.F. Tylecote

Jan Koran : Ironworking in the Bohemian Ore Mountains (after AD 1600). (In Czech). National Technical Museum, Prague, 1969, 62 pp.

A description of the iron industry which was using local materials in competition with a non-ferrous metals industry in its early phases. It went through the usual transition from direct to indirect processes with much of the metal going into sheet, some of which was tinned with local tin. The last blast furnace shut down in 1873, but the sheet-rolling side survived until 1886. The only plant that survived the rationalization of the 1930s was a seamless tube plant at Chomutov which used imported raw materials.

R.F. Tylecote

I.M. Allen, D. Britton, and H.H. Coghlan : Metallurgical Reports on British and Iron Age Implements and Weapons in the Pitt Rivers Museum. Oxford, 1970, 283 pp. and 28 plates. Price £2.50.

This is No. 10 in the Pitt Rivers Museum Series of Occasional Papers in Technology and the product of the cooperation of three experts in their respective fields.

The main part of this work consists of a series of chapters dealing with archaeological periods from the Copper to the Late Bronze Age. Each chapter starts with an introduction to the typology and chronology of the artifacts considered. Then follows a detailed examination of the 128 artifacts from the Pitt Rivers collection. This is in the nature of a catalogue giving a description accompanied by a drawing, chemical and spectrographic analysis, and a metallurgical examination; the latter is often illustrated by pen-and-ink drawings of the structures found and occasionally by the actual photomicrographs. This is rounded off by the addition of a chapter giving the results of similar but earlier work published in <u>Man</u> on four EBA ribbed halberds from the same collection.

The work is prefaced by a number of chapters describing the metallurgical features of the artifacts considered, the methods of study, and the arrangement of the work. All the analyses are grouped in a single series of tables, enabling comparisons of the compositions to be made.

We thus have a reference manual which allows those interested to compare quickly the results of an examination of an artifact with what is known of a similar artifact in the Pitt Rivers Museum. This would seem to be the main value of a work of this kind, and for the price there is no competition in the field. Of course, it is limited in scope to what exists in the Pitt Rivers Museum and failure to find comparative material here will mean that the seeker has a long search in front of him.

Most of the techniques used are fairly well known and generally accepted. Some are worth mentioning here. For example, when taking dental-type drillings, those from the surface are discarded and the drill is cleaned before the real sample is taken. Holes can be filled with metal-filled plastic which does not require heat and therefore cannot alter the metallurgical structure; if it is required to remove it at some later date, this can be done in acetone. For metallurgical examination, larger specimens are required since the surface is not representative of the bulk and therefore examination of a polished surface is not satisfactory. Small V-sections were therefore taken from the actual cutting edge of the blade of the weapon where possible. The position of these sections is indicated in the drawings.

It should perhaps be stated that much of the information is obtained from these sections and the Pitt Rivers Museum must be congratulated on allowing its artifacts to be cut up in this way. For too long we have been forced to rely on evidence obtained from the spectrographic analysis of dental drillings. This can only tell us what an artifact is made of and not how it was made nor give us data on the mechanical properties of the metal, and thereby an indication of the efficiency of a weapon or implement. To get all this we must face up to the removal of pieces as great as 0.125in cube. But the damage resulting from their removal can be made good by the use of plastic fillers.

In the course of the chapter on metallurgical techniques we are given a description of the late Dr Voce's experiments on casting in stone and bronze moulds and shown the structure of the metal cast into them. The structure of the bronze cast into the stone mould was coarser than that cast into the bronze mould, probably because of the slower cooling rate of the former due to the necessity of pre-heating the stone mould to a higher temperature to avoid cracking as a result of thermal shock. It is thought that grain size may be one way of deciding whether an artifact has been cast into a stone or a bronze mould. But the trouble here is that so many artifacts have been heated after casting and the original cast structure altered.

This report is an excellent example of what can be done to widen our knowledge of early metallurgy, and it is to be hoped that it will act as an example and inspiration to others.

R.F. Tylecote

Abstracts

The Editor would like to acknowledge the help he is now receiving with the Abstracts. He is very grateful to the following who are now actively participating : D.R. Howard, J.W. Butler, J.W. Haldane, P.S. Richards, T. Daff, H.F. Cleere, H.W. Paar, N. Mutton, E. Raub, A.P. Greenough, J.K. Harrison, J. Piaskowski, K. Poplawska.

GENERAL

J.E. Dayton : The problem of tin in the ancient world. (World Arch., 1971, 3, (1), 49-70) Tin ores are shown to be absent in the Near East, and possible sources of tin available to Near Eastern civilizations are examined. It is considered that these were mainly of Central European origin and that the metal was imported in the form of bronze via the Danube and east Anatolia. The author believes, on the basis of rather controversial epigraphical evidence, that the word annaku refers to be bronze. The paper does a valuable service in bringing attention to the problem of tin in the Near East, thus explaining the late arrival of true tin-bronzes and their replacement of the earlier arsenical coppers, but the theory of the import of high-tin bronzes and their dilution with local copper to make standard tin-bronze is not metallurgically convincing nor supported by sufficient archaeological evidence.

C.R. Dodwell : Gold metallurgy in the 12th century. (Gold Bull., 1971, 4, (3), 51-55). A short review of medieval gold-working based on Theophilus.

BRITISH ISLES

M.J. O'Kelly : An axe mould from Lyre, Co. Cork. (J. Cork Hist. & Arch. Soc., 1970, 75). An open sandstone mould with a matrix for a flat axe on each of the two sides. The edges of the mould are uneven and have not been used. The types date from 1650-1500 BC.

J.W. Haldane : A gold bracelet from Hope Wood, Wookey Hole, Somerset. (Proc. Somerset Arch. & N.H. Soc., 1969, 113, 99-101). The circumstances of discovery, a description, and the results of x-ray fluorescence spectroscopic analysis for the surface and interior of this LBA bracelet are recorded.

G. Joan Fuller : Early lead smelting in the Peak District : another look at the evidence. (East Midland Geographer, 1970, (33 & 34), 1-8). Starts with Roman and Anglo-Saxon times and takes us through the Domesday record and manorial rights. The paper concludes with a study of the inquisition of Ashbourne. The author makes out a good case for believing that the plumbariara of Domesday were lead smelters and not lead miners.

Joan J. Taylor : The recent discovery of gold pins in the Ridgway gold pommel. (Ant. J., 1970, 50, (II), 216-221). When the gold sword pommel from Ridgway (Dorset), discovered in 1885, was cleaned recently, 7 gold pins were revealed. These were used for functional rather than decorative purposes, being hammered flush with the foil. The pins are 1.2mm long and 0.47mm thick. This information throws light on the craft of goldsmithing in the Wessex I (Bronze Age) phase.

G.J. Wainwright : The excavation of a fortified settlement at Walesland Rath, Pembrokeshire. (Britannia, 1971, 2, 48-108). This small earthwork enclosure appears to have been occupied from the 3rd century BC to the end of the Roman occupation. Bronze smelting took place in the early phase and iron smelting followed in the Roman period. A number of crucible fragments, several spouted, can be paralleled by material from Glastonbury and Llanmelin. A bowl hearth with a crucible fragment in it was found in one of the peripheral buildings.

J.S. Wacher : Roman iron beams. (Britannia, 1971, 2, 200-202). The author summarizes the data on the seven beams or composite blooms found in Britain, from Chedworth (3), Catterick (2), Leicester, and Corbridge. The association with bath-houses is noted, and it is inferred that these beams were used for supporting hot-water boilers (of lead or bronze) that spanned the stokeholes of these buildings. The ends of the beams would have been bedded in the masonry of the stokehole walls; the prongs at the end of the Leicester example (which are paralleled by similar beams from the Saalburg in Germany) are seen to support this explanation.

Roman Britain in 1970. (Britannia, 1971, 2, 243-304). In this annual survey of work during the year, the following are briefly noted :

Dolaucothi (Carms) : Further surveying of the gold-mining complex has revealed more aqueducts.

Bowes (Yorks NR) : Metalworking activities identified at the fort.
Scarcliffe Park (Derbys) : Iron slag and charcoal in 2nd century site.
Ancaster (Lincs) : 2nd century ironworking.
Winterton (Lincs) : 3rd century bronze working
Godmanchester (Hunts) : Bronze-working slag and crucibles in waste from mansio.
Colchester (Essex) : "Belgic" huts (post-AD 43) probably used by native bronze workers, making military equipment; finds include slag, furnace material, scrap metal, crucibles, stamped bronze ingot, die for stamping phalerae.
Cheddar (Som.) : "Iron smelting features" of late 1st-early 2nd century AD.
Poundbury, Dorchester (Dorset) : 3rd century ironworking in building underlying 4th century cemetery.
Leigh Park, Havant (Hants) : Late 3rd-early 4th century bronze-smelting building.
Chichester (Sussex) : 1st century AD metal-working area (hearths, crucible fragments).
Holtye (Sussex) : Large Roman ironworking settlement, 1.6 km west of London-Lewes Roman road (here surfaced with iron slag).
Wye (Kent) : Ironworking and smelting hearths of late 1st to early 3rd century AD.

Philip Rahtz : Excavations on Glastonbury Tor, Somerset, 1964-6. (Arch. J., 1970, 127, 1-82). The earliest phase of this feature, which dominates the Isle of Glastonbury, was a Dark Age (post-Roman) stronghold or religious site. Metalworking was practised during this phase, as evidenced by a crucible and a ring-shank (described by the excavator as a lampholder, but correctly identified by Dr W.H. Manning).

Investigations and Excavations during the Year (1971). (Arch. Cant., 1970, 85)
Springhead : Hearths with evidence of iron and bronze working, plus small bowl hearth associated with "bronze droppings" in temple complex.
Hammermill Farm, Biddenden : Excavation of the 17th century blast furnace - wheel pit for bellows located.

P.S. Gelling : A metalworking site at Kiondroghad, Kirk Andreas, Isle of Man. (Med. Arch., 1969, 13, 67-83). Excavation revealed evidence (including ingot moulds and pattern stones) of iron and bronze working at and in the vicinity of the site. There were two phases of occupation, in the late 7th-8th centuries and the 9th century AD.

J. Gould : Excavation of the 15th century iron-mill of Simon Montford at Bourne Pool. (Trans. S. Staffs. Arch. & N.H. Soc., 1969-70, 11, 58-63).

G.R. Morton and J. Wingrove Metallurgical considerations of early bloomeries in South Staffordshire. (ibid., 64-66). Probably a water-wheel operated bloomery. Analyses of ores and slags suggest that the iron produced was of moderate phosphorus content and that lime was added to the extent of 7% to flux the siliceous gangue, thus increasing the extractive efficiency.

G. Rees : Copper sheathing (of ships). An example of technological diffusion in the English merchant fleet. (J. Transport Hist., 1971, 1, (2), 85-94). Summarizes the advantages and disadvantages of copper sheathing on wooden vessels, first introduced in 1761 on the Frigate Alarm. Merchant vessels were coppered from about 1770 on. By the end of the century, sheathing was especially used in vessels built or maintained at Liverpool, Lancaster, and Chester, as shown by details in Lloyd's Register. This was attributed to the nature of shipping activities at these ports. The source of the copper is not considered.

W.N. Jenkins : Death of the puddler. (British Steel, 1971, 14, 27-28). A brief and nostalgic attempt to convey the atmosphere of the 19th century puddler at work, and to give some idea of his social standing.

K.C. Edwards : Bell-founding at Loughborough. (East Midland Geographer, 1955, 4, 53-54). An historical account of one of the few bell-founding centres still in existence in Great Britain. Emphasizes the changes in conditions affecting location from the earliest times to the present day.

D.R. Ingram : A note on bell-founding in Nottingham. (East Midland Geographer, 1966, 26, 107-109). The history of this industry in its geographical setting from the 14th century to its closure in 1791.

B.L.C. Johnson : Distribution of factory population in the West Midlands conurbation. (Trans. Inst. Brit. Geog., 1958, 25, 209-223). He uses the registers of HM Factory Inspectorate and incorporates a detailed account of the iron foundry industry in the area. The same author has written on 'The iron industry of Cheshire and North Staffordshire', 1688-1712, in Trans. N. Staffs. Field Club, 1954, 88, 32-55.

K. Warren : The Derbyshire iron industry since 1780. (East Midland Geographer, 1961, 16, 17-33). Relates ironmaking resources of east Derbyshire to the early iron industry of the area. It then concerns railways, technical changes in the iron trade, and their effects on the landscape, and concludes with reasons for the failure of the smallest industries.

R.F. Tylecote : Recent researches in 19th century Northumbrian blast furnace sites. (Ind. Arch., 1971, 8, (4), 341-359). An addition to the work of Lowthian Bell, Hoskinson, and G. Jones on the same theme. New light is thrown on the furnace at Brinkburn near Rothbury by the finding of a blast furnace construction drawing dating to 1871. Further work has been done on what was to become Sir W.G. Armstrong's works at Ridsdale, both on the ore quarries and the ruins of the blowing engine house. The latter has been fully surveyed and the elevations plotted by photogrammetry, which must have been one of the first applications of a new technique in industrial archaeology.

D.G. Watts : Changes in the location of the South Wales iron and steel industry 1860-1930. (Geography, 1968, 53, (3), No. 240, 294-306). This well documented paper deals with the abandonment of the Coal Measure ironstones, the migration of the iron and steel industry, the cost of ore haulage to the inland works, and the location of the new steelworks. The writer corrects some popular misconceptions, especially 'migration'. The emphasis is on human and chance factors illustrating how these overcame physical handicaps. Contains map of South Wales ironworks in 1960 and a table of South Wales blast furnace plants in 1860. (NB This paper refers to a thesis by J.P. Addis on 'The heavy iron and steel industry of South Wales 1870-1950', University of Wales PhD, 1957).

Michael Robbins : The first Sussex railway. (Railway Mag., 1971, 117, (843), 355-357). Letters from William Jessop of the Butterley Iron Company to George Shiffner, now at the East Sussex County Record Office, show that despite competition from Bailey, Ward and Co., who were situated "at the south foot of Blackfriars Bridge", Jessop's plans for the railway from Offham chalk pit down an inclined plane to the Papermill Cut of the Ouse Navigation were accepted. Rails 3ft long, waggon wheels, a large wheel weighing $1\frac{3}{4}$ tons (for incline machinery ?), and all other equipment were sent from Butterley via Gainsborough and London in 1808. The line opened in March 1809 and was used until about 1870, when navigation on the river above Lewes ceased.

W. Simpson : Rules and orders of an early foundry union. (Foundry Trade J., 1971, 130, (2839), 437-448). A reprint of the rules and orders to be observed by the Friendly Society of Operative Iron Moulders of Great Britain and Ireland, published 1837

(Anon.) : Dolphins Anonymous. (Foundry Trade J., 1971, 130, (2837), 364). Dolphin lamp standards on the Victoria and Albert Embankments in London were cast by Masefield & Co. and Holbrook & Co., Chelsea, and bear the date 1870. Others were added round and near the County Hall in 1910, 1933, and 1964. Rather unexpectedly, one standard of this design can be seen at Cliffe Castle, Keighley and two at the main doorway of the City of London School. Further standards are now to be made for the extension of the South Bank Walk (1971, 131, (2860), 431).

S.H. Beaver : The Potteries : a study in the evolution of a cultural landscape. (Trans. Inst. Brit. Geog., 1964, 34, 1-32). Contains references to ironworks.

K. Warren : The Sheffield rail trade, 1861-1930. (Trans. Inst. Brit. Geog., 1964, 34, 131-157). This paper is concerned with wrought-iron rail production and the growth of the iron industry in Sheffield. It analyses factors in the early concentration of steel rail production in Sheffield, the recovery, the boom, the depression, and the growth of competition. Contains many maps, graphs, and references.

K. Warren : Regional economic growth and public policy. (Urban Studies, 1966, 3, (3), 185-199). This paper is concerned with the fact that unemployment and especially expansion in metal-using industries is focussed in the already prosperous areas, employment in primary metals in the less prosperous ones. He is also concerned with the large bulk movement of steel.

J.C. Goodridge : The tin-mining industry : a growth point for Cornwall. (Trans. Inst. Brit. Geog., 1966, 38, 94-104). Analyses post-war fluctuations in world prices and production of tin and new techniques of mining resulting in the reassessment of former mining areas. The results of political disturbances in the Congo and Indonesia are noted as is the work of the Cornish Mining Development Association.

D.C. Pocock : Specialised industrial towns as service centres. (Trans. Inst. Brit. Geog., 1966, 40, 97-109). Describes the way iron-ore quarrying, pig-iron production, and then steelmaking in the northern parts of Lincolnshire and Northamptonshire led to the creation of the two towns of Scunthorpe and Corby. These are the only two centres of iron and steel production located on home orefields, and currently produce one-fifth of Britain's pig iron and one-seventh of the national steel output. The rapid growth of these two towns and their influence on their hinterlands is also discussed.

J. Hill : The development of an industry and an institute. (Brit. Foundryman, 1969, 62, (6), 211-215). A printed presidential address giving a brief account of British foundry work, mainly since 1904, when the Institute of British Foundrymen was formed. There are comparisons drawn with US practice and development. The author's outline is, frankly, unhistorical, but for those wishing to have an outline of developments in the 20th century the rest of the paper gives a useful conspectus.

Bar mill jubilee at Templeborough. (Brit. Steelmaker, 1971, 37, (7), 11-13). Templeborough's bar mill's golden jubilee. (Steel Times, 1971, 199, (8), 667-668). Brief accounts of the Templeborough bar mill at the Rotherham works of the former United Steel Companies from 1921. Original format and performance are compared with subsequent improvements and modern performance in the changed but still recognisable mill.

EUROPE

L.U. Salkield : Ancient slags in the south-west of the Iberian peninsula. (La Mineria Hispana y Iberoamericana, Vol. I, 1970, 85-98; VI Congreso Internacional de Mineria, Leon, 1970). Gives analyses of early slags and litharge from Rio Tinto, Tharsis, and other areas nearby, together with analyses of jarositic earths (i.e. silver-bearing minerals). Concludes that, contrary to popular belief, most of the ancient slags in the SW corner of the Iberian peninsula were produced by smelting jarositic earths to extract silver and not from smelting cuprous pyrites. At Rio Tinto, the ratio of these slags is 15:1 respectively. This paper contains a useful sketch by Professor David Williams of a section through the Rio Tinto mining area showing the original pre-Roman conditions of the deposit.

E.V. Chernenko : The armament of the Scyths. (Kiev, 1968). In Russ. A study of cuirasses, shields, and greaves covering the period 6th-3rd century BC. The traces of 126 cuirasses made of iron scale armour were found in the kurgans.

R. Pleiner : Smithing technique in Bavaria in the Roman period. (Bayerische Vorgeschichtsblätter, 1970, 35, (1/2), 113-141). In Ger. A chemical and metallographic examination of 15 ferrous artifacts mostly from the area south of the Danube, giving details of the smithing techniques used. Comparisons are made with objects from a wider central European context.

R. Pleiner : The trade in iron in east central Europe in the 4th to 9th centuries AD. (Antikvariskt Arkiv 40. Early Medieval Studies, 3, 13-21). In Ger. In the Roman period there was both internal and external trade in the areas inside and outside the Limes. An example of this is the pattern-welded swords which are believed to have originated in the Rhineland and were traded as far as SE Poland. This trade was upset in the Migration period. In the Slav period the author concludes that there is some evidence of external trade in sophisticated implements into the Slav areas which supplemented the material made by the more primitive techniques of the local smiths. There was an internal trade in "axe" bars in the same area but few exports.
The metal of the Roman period was low in phosphorus but later the use of small local deposits caused an increase in the phosphorus content of the iron. It is probable

that steel with its low phosphorus content was obtained by the selection of high-carbon low-phosphorus regions of the bloom and not imported from areas still producing low-phosphorus iron.

H. Hingst : Ironworking in the state forest, Flensborg. (In Siedlung, Burg, und Stadt, Berlin, 1969, 423-437). In Ger. Several groups of slag and the remains of bowl furnaces were found. The height of the latter was 120-140cm. It was estimated that each furnace had been rebuilt 20-30 times. The accompanying material is dated to the 12th century AD.

J. Klepper : Prehistory of the Luxembourg iron and steel industry. (Rev. Techn. Lux., 1971, 63, 39-57). In Fr.

A. Sprunk : Some aspects of the history of the Luxembourg iron and steel industry in the 18th century. (Rev. Techn. Lux., 1971, 63, 58-66). In Ger.

K.C. Edwards : Historical geography of the Luxembourg iron and steel industry in the Duchy. (Trans. Inst. Brit. Geog., 1961, 29, 1-16). Describes the most important industry in the Duchy from about 1500 to the present day. Makes special reference to the exports. A valuable paper. Maps.

ASIA

Beno Rothenberg : The Sinai Archaeological Expedition (1967-70). (Ariel, 1971, (28), 59-64). A brief report with reference to Chalcolithic and later Egyptian copper and Turquoise mining activities in the southern part of the peninsula.

H.H.E. Loofs : Discovery of traces of iron-working at U-Thông in central Thailand. (Rev. Hist. Min. Mét., 1971, 3, (1), 109-110). In Fr. Known in central Indo-China around the 6th-5th century BC. It came suddenly after a Neolithic period and, as there is no trace of slag, could have been imported. Further to the north, in Laos, there are slags dated to the 1st century AD. According to Solheim the Phillipines obtained knowledge of iron about 4th to 2nd century BC, probably from Vietnam, but again there is no trace of slag from this period. Others think that iron-working came to the Phillipines during the 1st century AD from Indonesia. Tom Harrisson has found slag in Borneo near the Sarawak River together with tuyeres dated to the 12th century AD.

In Thailand, in the mountains separating Thailand from Burma, at Tha-Muang near U-Thông, iron and slag were found in an Indianized capital of the 6th-11th centuries AD. The finds are awaiting carbon-14 dating, but a date of the 8th-9th century AD is suggested as being possible. It is suggested that the introduction of iron into Cambodia could be due to Indian colonists during the Fou-Nan period.

T. Harrisson and S.J. O'Connor : Excavations of the prehistoric iron industry in West Borneo. Part I and II. Ithaca, NY, 1969. This paper gives the results of excavations and surveys in the delta of the Sarawak River. The authors found a large amount of slag with fragments of tuyeres or cylindrical crucibles. No traces of the actual furnaces came to light. The metallurgical activity dates from the 12-13th century AD; whether it has Chinese or Indian associations is not clear.

AFRICA

K.M. Barbour : The distribution of industry in Egypt : a new source considered. (Trans. Inst. Brit. Geog., 1970, (50), 155-176). Refers to the extraction and refining of iron and other ores,

H. Amborn : The problem of iron production in the Meroitic kingdom. (Paideuma, 1970, 16, 71-95). In Ger. On the basis of excavations in the 19th and early 20th centuries, on the western part of the site, the author wrongly concludes that iron was not worked at Meroë and that the "assumed" slag heaps contain the waste of other industries. This conclusion has now been shown to be wrong by the more recent excavations by Shinnie on the northern and eastern parts of the site, which produced incontestable evidence of iron-working, including smelting furnaces (see Tylecote : HMG Bull., 1970, 4, (2), 67-72).

This paper has some value in its detailed analysis of the bronze and iron grave finds from some of the Meroitic sites, showing how few were the examples of ironwork that they contained. It is important to note that these data belong to the last few centuries BC, while the intensive ironmaking period at Meroë belongs to the first two or three centuries AD.

J. Haden : Okebu iron smelting. (Uganda J., 1970, 34, (2), 163-170). The furnace was a type of bowl furnace built into a shallow pit 8ft by 6ft and 2ft deep. The furnace was built up against the side of the pit and blown by a single inclined tuyere 26in long and 1.5 in bore provided with air from a pair of valveless pot bellows. The tuyere terminated about halfway up the 30in high clay-walled furnace. The ore was limonitic, containing about 80% Fe_2O_3. It was broken into shilling-sized pieces (0.9in dia) but not roasted. The charge consisted of 40lb ore, 60lb hardwood charcoal, and 40lb of slag from a previous smelt. The product was a mass of slag and iron weighing about 6lb which produced 2-3lb of iron. Some of the slag was tapped; the rest seems to have collected at the bottom of the furnace.

AMERICA

C.M. Abbott : Early copper smelting in Vermont. (Vermont Hist., 1965, 33, 233-242). This plant started smelting copper from the local mine at South Strafford around 1830. This arose out of the earlier production of copperas (ferrous sulphate) and cement copper. In 1830 two blast furnaces were in operation and two more were building. By 1833 there were at least 7 furnaces roasting beds, charcoal kilns, a sulphur kiln, a calciner for venetian red, a dam, water-wheel, and air regulator. In 1833, when Isaac Tyson became superintendent, the blast furnaces were 12-20ft high (probably including the stack) and 2-4ft square. The single tuyere projected from the back, and slag and metal were tapped from the front. In 1834, when his record ends, Tyson was experimenting with anthracite and hot blast. By 1839 the works seems to have been closed, when the head smelter moved to Plymouth and later went to the Revere Copper Works in Port Shirley.

SCIENTIFIC EXAMINATION

H.G. Bachmann : Early metallurgy and modern analysis : methods, examples, and practical results. (La Mineria Hispana y Iberoamericana Vol. I, 1970, 15-29; IV Congreso Internacional de Mineria, Leon, 1970). In Ger. Examples of slags taken from 7th century Anatolia (Cu and Fe), 17th-12th century Israel (Cu), and lead ore or slag from West Germany. The techniques used include x-ray fluorescence, wet chemistry, x-ray diffraction, electron and light microscopy.

H.G. Bachmann : Investigation on pre- and protohistoric copper smelting slags. (Zeit. Erzbergbau u. Metallh., 1968, 21, (9), 419-424). In Ger. A more detailed treatment of the above. The slags came from Alaca Huyuk in Turkey and Timna in Israel. Two types of slag were identified : (1) inhomogeneous slags or accretions from the roasting of sulphide ores and (2) homogeneous slag from the smelting of oxide-type ores. The author has reason to think that it may prove difficult to distinguish roasting and smelting slags from sulphide ores.

H. Barker and J. Rawson : A Chinese gilt bear from the Oppenheim Collection. (Brit. Mus. Quarterly, 1971, 36, (1-2), 53-55). Examination of the gilding and corrosion products suggests that the object is modern and not of the Han Dynasty (206BC to AD 220) as previously thought. This confirms doubts entertained on stylistic grounds.

K. Roesch and E. Lindeman : Secondary carburization of iron at Remscheid as an experiment in primitive technology. (32nd Meeting of VDEh Historical Committee, Düsseldorf, 29 April 1969). In Ger. The pieces of iron were heated between several layers of leather in a crucible filled with charcoal, which resulted in very homogeneous carburization.

V. Wollman : The value of metallography in the study of some archaeological finds. (Apulum, VI, Clug, 629-642). In Romanian. A bloom of the late La Tène to Roman period from Piatra Craivii contained an average of 0.009%P and 1.94%C. Analyses of slags and other iron objects from the same area are also given.

R. Wyss : Documents on the art of Celtic swordsmithing. (In Provincialia : Festschrift to Robert Laur-Belart. Basel-Stuttgart, 1968, 664-680). In Ger. A study of swords and scabbards from La Tène Switzerland using metallographic techniques. The author emphasizes the use of acid etching to reveal the patterns and the effects of welding. He gives the results of a detailed examination of a sword made by piling (welding) several layers of mild steel. It was clear that punching had been used to accentuate the pattern on the surface of both blades and scabbards during the late La Tene period.

Adon A. Gordus : Neutron activation analysis of coins and coin streaks. (Symposium on the Analysis of Ancient and Medieval Coins, Royal Numismatic Society, London, 1970). Demonstrates the value of two non-destructive techniques of coin analysis. The coins were mostly Persian from the Sasanian (224-651 AD) and the Umayyad periods. The first technique involves the irradiation of the coin in a low-intensity beam of neutrons from a radioactive source in a neutron "howitzer". This can be used for silver and gold and takes 2.5 min per coin. In the second technique the coin sample is rubbed on etched quartz tubing to give a streak weighing less than 0.0001g, and 100-200 coins can be so tested per day. About 4o streaks can be irradiated per day in a nuclear reactor and this gives Ag, Au, Cu and sometimes As, Sb, and Zn. The second method is the more valuable, but both methods overcome the problem of residual silver radioactivity.
Most of the conclusions relate to the gold content of the silver, which is considerably in excess of today's values. These figures are used as indicators of local sources and it seems that there were sources of silver ore in Iran at this time which are not known today. The silver was not obtained from lead ores which today contain at most 500-700 g of silver per ton. To obtain the silver from such a source would mean a vast surplus of lead, no signs of which can be seen. Yet the analyses of Umayyad coins show the presence of 0.42-1.85%Pb, a figure which many think is symptomatic of cupellation. It is possible, however, that such cupellation was intended as a purification process for a Cu-Au-Ag ore, which would need additions of lead to reduce the copper content.

TECHNIQUES

R.F. Tylecote, J.N. Austin, and A.E. Wraith : The mechanism of the bloomery process in shaft furnaces. (JISI, 1971, 209, 342-363). Gives the results of an experimental smelting programme based on 30cm dia. shaft furnaces of the Roman period found at Ashwicken (Norfolk) - JISI, 1962, 200, 19-22 - and Pickworth (Lincs). This type of furnace is capable of producing blooms weighing 6-8kg from carbonate ores. The carbon content could be controlled in the range 0-1.8%C by altering the fuel/ore ratio. Tap slag could only be produced with low fuel/ore ratios and metal of low carbon content. A forced draught of 300 l/min was necessary and attempts were made to use induced draught, but were unsuccessful. There seemed to be no need to have an active bed greater than 50cm deep, and thus the Ashwicken/Pickworth furnaces were probably no higher than the 1.3m found during excavation.

Henry Cleere : Ironmaking in a Roman furnace. (Britannia, 1971, 2, 203-217). This is a slightly modified version of the paper originally published separately by The Iron and Steel Institute (HMG Bull., 1970, 4, (2), 89). It describes smelting experiments using a reconstruction of a late 2nd century AD Roman furnace of the type found at Holbeanwood, Sussex.

Heather Lechtmann and Arthur Steinberg : Bronze joining : a study in ancient technology. (In Art and Technology : A Symposium on Classical Bronzes, pp. 5-35, M.I.T., 1970). The authors have used the opportunity provided by an exhibition of 325 classical bronzes to demonstrate some of the joining techniques used. These comprise mechanical methods, often sealed with lead; lead-tin solders on the handles of 5th-4th century BC Greek and Etruscan vessels; a repair by casting-on a new part; and joining pieces of a statue by welding to overcome the difficulty of casting a large one. Much of the paper is concerned with the details of this latter and most interesting process applied to a Roman statue. Large oval areas were left between the castings or cut out later, and filled with weld metal of similar composition to the parent metal in such a way as to make a good metallurgical bond not unlike a modern fusion weld. It would appear that shrinkage cavities occurred in the centre of the oval areas after filling and that these were in turn filled with small rectangular patches. The paper is well illustrated with photographs and photomicrographs but it is a pity that the metallurgist does not learn from the archaeologist and give scales to his photographs. If this had been done here, it would have been possible to have given some indication of the size of the oval areas. The alloys used in the Roman statue were leaded bronzes containing 3.1-6.6%Sn and 20-38.5%Pb. An 8th century BC Geometric bird contained 10-13%Sn and no Pb.